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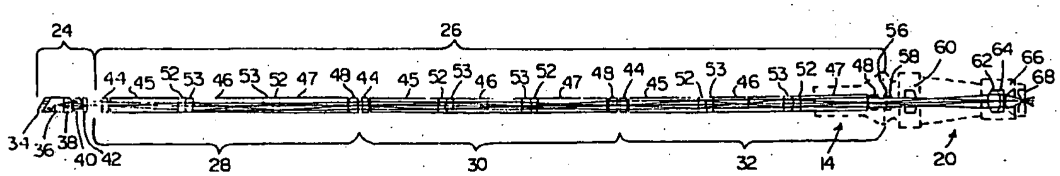


(57) Abstract

In an endoscope having a focusing ocular, a disposable probe includes a transfer module assembly with one or more relay modules (28, 30, 32), and an objective group (24) comprised of a distal glass window (34), a molded plastic prism (36) and three molded plastic lenses (38, 40, 42). Each relay module contains an entry glass rod, an intermediate glass rod, and an exit glass rod, each rod having flat end surfaces, and two identical molded plastic doublets. In certain embodiments, each relay module further includes identical molded entry and exit field lenses. In one preferred embodiment, the ocular comprises several glass elements, including an axially movable focusing element and two non-movable doublets. The disposable probe introduces predetermined optical aberration into the image, and the focusing ocular specifically corrects this aberration. The ocular is typically not disposable. A single curved surface is formed on the distal glass window of the probe; all other curved optical surfaces of the disposable probe are formed on molded plastic members, thereby reducing the cost of the probe sufficiently to be cost-effective for single patient, disposable use.

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# DISPOSABLE ENDOSCOPE

## BACKGROUND OF THE INVENTION

### Field of the Invention

The present invention relates to endoscopes and, more particularly, to endoscopes manufacturable sufficiently inexpensively to be disposable after single patient use, while being at least equal in optical performance to conventional endoscopes requiring sterilization.

### Description of the Prior Art

Endoscopic or least invasive surgery has many advantages over conventional "open" surgery. Patients who have undergone endoscopic surgery rather than open surgery experience vastly less trauma and much faster recoveries, leading to improvement in the quality of health care together with reduction in the cost of health care. These advantages have spurred extensive development of endoscopes.

The term "endoscope" as used herein refers to an elongated optical probe capable of presenting a visible image of the interior of a body cavity, joint, organ or the like to a physician on either an eyepiece or a video screen. The endoscope is typically introduced into the body cavity through a bore in another device (also typically referred to in the art as an endoscope, or as an endoscope sheath) including a light source as well as other bores for introducing surgical instruments, water, air, suction and the like. Endoscopes as optimized for various surgical procedures are referred to as arthroscopes, cystoscopes, proctoscopes, laparoscopes and the like.

The art has for some years sought to develop a suitable disposable endoscope. The surgical requirement of absolute sterility is difficult to satisfy with conventional endoscopes as these complex instruments are not readily amenable to conventional sterilization techniques. The spread of infectious disease is of particular concern and requires that care and caution be employed during the sterilization process. Accordingly, there is a strong need for a suitable disposable endoscope, that is, one made sufficiently inexpensively as to be cost-effective for disposal after single-patient use.

Endoscopes typically consist of a distal objective for forming an optical image of the interior of the body cavity, bone, joint or organ, a transfer module (sometimes termed a "relay section") for transmitting the image from the distal end of the probe to its proximal end, and an ocular at the proximal end of the transfer module for presenting the image to an eyepiece, a video camera or the like. Typically, the ocular will contain the movable focusing components of the endoscope.

One of the difficult tasks in designing a satisfactory endoscope is that of designing the transfer module. The transfer module must be capable of transmitting the image formed by the objective to the ocular without significant loss of brightness or sharpness in the image. Early endoscope designs included numerous glass refractive elements, each requiring extensive polishing. The high cost of manufacture precluded use of these designs for disposable endoscopes.

More recently it has been suggested that the refractive optical elements of the transfer module should be molded of plastic, while the transmitting elements could be formed of much less expensive plano glass rods, i.e. glass rods having flat ends. Indeed, providing the curved surfaces in optical systems in molded plastic members, and using glass only for flat surfaced elements, is suggested by optical design textbooks; see, e.g., <u>The Handbook of Plastic Optics</u>, <u>2nd</u>

edition, published by U.S. Precision Lens, Inc. (1983), at page 86. However, despite this suggestion, there is no prior art disclosure or teaching of an endoscope providing adequate optical performance capable of manufacture at sufficiently low cost to be disposable.

Prior art endoscopes have typically been designed such that the objective provides a self-corrected image to the transfer module, the image then being transmitted with as little further aberration as possible to an ocular group. It is also known to employ the transfer module to correct aberration introduced by the objective. In either case the image presented by the probe to the ocular is fully corrected. Typically the ocular designs employed have included two doublets placed back to back; this form permits separating the doublets at an afocal space. The first doublet is employed as a simple magnifier of the image, and the second doublet as a focusing element to allow a video camera to form the visible image on a display screen. However, this essentially simplified ocular design requires the image formed by the combination of the objective and the transfer module to be self-corrected. The cost of manufacture of suitable objective and transfer module components is too great for single patient disposable use.

Prior endoscopes have commonly also employed a fore-oblique prism in the tip of the endoscope to provide an off-axis field of view, that is, centered about an axis at an angle to the optical axis of the probe, so that by rotating the probe the surgeon has an effectively wider field of view than otherwise possible. In the prior art, such fore-oblique prisms have been manufactured by separately manufacturing two or three prisms of glass of high refractive index, separately coating the appropriate surfaces with reflective material, bonding the prisms together in an assembly jig requiring very high precision, and finally grinding the outer surface of the assembly to the desired cylindrical form. These manufacturing steps are very labor intensive and time-consuming, and render such

fore-oblique prisms in the prior art much too expensive for use in a disposable device for single patient usage.

Another constraint on endoscope design arises because from time to time during surgery the surgeon may wish to change the endoscope viewing angle, that is, to vary the angle between the center of the field of view and the optical axis of the probe. While endoscope designs have been proposed permitting variation of the viewing angle by moving a pivoted mirror or the like at the distal tip of the endoscope, these designs have been highly impractical. Variation of the viewing angle is possible in practical endoscopes only by removing a first probe from the surgical portal and substituting a second probe having a different viewing angle. To do so employing conventional re-usable endoscopes requires sterilization of several different endoscopes at substantial cost. If a video camera were being used to display the image, as is typical, this procedure would normally also necessitate disconnecting the ocular of the first endoscope from the video camera and reconnecting a second endoscope. It would be desirable to provide disposable endoscope probes having differing viewing angles all mating with the same ocular, so that the probe could be replaced conveniently and discarded at reasonable cost if the surgeon desired to change viewing angles.

Endoscopic objectives found in the prior art have required glass elements of very high refractive index and having large differences in their spectral dispersion to provide control of optical aberration. These prior art designs have been limited to all-spherical surface design forms because of the cost of producing aspheric surfaces in glass. More specifically, one prior art endoscope objective design form uses a plano-concave flint glass element of very high refractive index preceding the prism element, a high index of refraction convex crown glass element bonded to the preceding prism element, a high index of refraction biconvex crown glass element, and a doublet including one element each of crown and flint glass. In the prior art, the high

cost of production of these elements, having optical surfaces sufficiently steep to require individual polishing, had precluded use of this design for a disposable endoscope.

Prior to the present invention there had been no endoscope design including a disposable probe that provided satisfactory optical performance, including convenient variation of viewing angle, while being manufacturable sufficiently inexpensively to be cost-effective for single-patient disposable use. The present invention satisfies these needs of the art.

This patent application discloses in detail endoscopes optimized for laparoscopic and arthroscopic surgical procedures. The endoscope optimized for arthroscopy, that is, for examination of the bones, tendons, cartilage, and ligaments of skeletal joints, especially knees, shoulders and hips, comprises a slender probe capable of fitting between closely spaced structures. Slight degradation of the optical image, particularly as to the ultimate resolution or "sharpness" of the image and the uniformity of illumination in the image, may be acceptable in an arthroscope of suitably reduced diameter.

The endoscope optimized for laparoscopic surgical procedures disclosed herein is used to view organs, vessels and the like, particularly in the abdominal and chest cavities. Such an instrument must provide an image of the highest possible resolution to enable the surgeon to see each intimate detail of the diseased or damaged organ. Uniformity of illumination throughout the image is also very critical. However, a laparoscope may be somewhat more bulky than an arthroscope.

## SUMMARY OF THE INVENTION

It is an object of the present invention to overcome the above-mentioned disadvantages of prior art disposable endoscopes.

More particularly, it is an object of the invention to provide an endoscope capable of providing a satisfactory

visual or video image to a surgeon of the interior of a body cavity, bone, joint, vessel or organ, and including a probe manufacturable sufficiently inexpensively to be cost-effective for disposability after single-patient use.

It is a particular object of the invention to provide an objective design for an endoscope having its principal optical elements molded of plastic, and to thus greatly lower the cost of the endoscope as compared to prior art designs.

It is a further object of the invention to provide a disposable endoscope probe and, in particular, a disposable endoscope probe comprising a prism for providing oblique viewing angles requiring no complex and time-consuming assembly operations.

It is an object of the present invention to provide a transfer module for an endoscope that does not employ long glass rods but employs only short glass rods, rendering the device much less susceptible to breakage.

It is an object of the invention to provide an endoscope featuring essentially interchangeable disposable probes used with the same ocular and, in particular, to provide a selection of disposable probes having various viewing angles between the center of the field of view and the axis of the probe.

It is another object of the invention to provide a number of probes for an endoscope, each probe providing a different viewing angle, the probes differing only in the design of the prism but using essentially common components elsewhere, thus substantially economizing probe manufacture.

It is a further object of the invention to provide an endoscope comprising a disposable probe, including an objective group and a transfer module assembly, and a focusing ocular. The ocular may be disposable or non-disposable.

It is a further object of the invention to provide an endoscope comprising a disposable probe and a focusing

ocular, wherein certain residual aberration is present in the image formed by the disposable probe and transferred to the ocular, and wherein the ocular corrects the residual aberration in the image formed by the probe.

It is a further object of the invention to provide an endoscope comprising a disposable probe including an objective, a transfer module and a coupler for coupling the probe to a conventional focusing ocular, wherein the coupler compensates for predetermined aberration in the image transmitted thereto by the transfer module from the objective.

The above objects of the invention and needs of the art are satisfied by the present invention of an endoscope comprising a disposable probe and a focusing ocular. The disposable probe is sufficiently inexpensive to be cost-effective for disposability after single patient use. The endoscope of the invention suffers no performance disadvantage compared to conventional non-disposable endoscopes.

The disposable probe of the present invention comprises an objective group at its distal end and a transfer module assembly. The objective group comprises a single glass window element at its distal end, a molded plastic prism and three molded plastic elements.

The transfer module assembly comprises a number of identical relay modules. In the preferred embodiment, each relay module comprises two doublets interspersed by plano-surfaced glass rods. Each relay module of the transfer module as optimized for laparoscopy also comprises entry and exit field lenses. The entry and exit field lenses of adjoining relay modules may be integral. The doublets each include two identical molded plastic elements. The field lenses, where used, are also identical to one another, and are also molded of plastic.

The disposable probe introduces certain predetermined residual aberration into the image presented to the focusing ocular. The focusing ocular corrects for this aberration,

and optically couples the disposable probe to a video camera or the like.

The focusing ocular comprises at least one movable focusing element and four further lens elements. Typically, the elements of the ocular are formed of glass using conventional polishing techniques, such that the ocular is non-disposable, and is coupled to the disposable probe for use. However, the ocular may also include molded glass or plastic elements, and thus may also be disposable. It is also within the scope of the invention to correct the aberration in the image presented by the probe using an afocal (i.e., non-focusing) coupler. In this case the coupler corrects the aberration in the image, and connects the probe to a conventional focusing ocular, as used with non-disposable endoscope probes.

Relatively steep spherical surfaces are formed in the lens elements of the ocular (or coupler) to correct chromatic aberration, field curvature, and astigmatism in the image presented by the transfer module. In the preferred embodiment, no aspheric surfaces are required in the ocular.

A generally cylindrical molded plastic prism in the objective is used to provide a field of view angled with respect to the optical axis of the probe. The prism is a unitary solid element. An inclined distal end of the prism is directly juxtaposed to the rear surface of a glass window element at the distal end of the probe. Light entering the glass window enters the prism through a first angled end, reflects internally at two reflecting surfaces formed by recesses in the prism, and exits the prism along the optical axis of the probe. The refractive index of the plastic of the prism and the angle at which the light rays meet the plastic/air interface of at least one of the reflecting surfaces are such that reflection occurs by total internal reflection within the prism. Accordingly, no more than a single reflecting surface of the prism requires a reflective coating, providing a further economy. The components of the

objective, apart from the prism, are identical in several embodiments of the probe having differing viewing angles.

The overall design of the endoscope of the invention thus provides the advantage that the only glass elements employed in the disposable probe are the window at the distal end of the probe, a plano surfaced window at the proximal end of the transfer module, and the plano surfaced glass rods of the transfer module. These elements are all relatively economical to manufacture. The objective contains the window, the prism, and three lenses (two of which are identical) while the transfer module includes a limited number of types of lens elements. Each of the lenses in the probe is molded of plastic and accordingly is relatively inexpensive in quantity. The lenses of the disposable probe and the prism may be molded of glass instead of plastic; these alternatives are anticipated to become increasingly attractive as glass molding technology matures.

The non-disposable focusing ocular contains glass lenses, each including only spherical surfaces. The use of glass elements in the focusing ocular lends durability, and the cost of these glass elements is not significant to the overall cost effectiveness of the endoscope of the invention. As noted, the elements of the ocular may ultimately be molded of glass or plastic, such that the ocular would also be disposable. Further, the disposable probe may comprise a disposable afocal coupler, for connecting the transfer module to a conventional ocular.

Other objects and advantages of the present invention will become apparent from the following description of the preferred embodiment taken in conjunction with the accompanying drawings, wherein like parts in each of the several figures are identified by the same reference characters.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an exploded side view of an endoscopic imaging system according to the present invention.

Fig. 2 is a partially diagrammatic side view of the optical components of the disposable probe and focusing ocular of the endoscope of the present invention.

Fig. 3 is a partially diagrammatic view in longitudinal section of the objective assembly of the disposable probe of the endoscope of the present invention.

Fig. 4 is a partially diagrammatic side view of one of the relay modules of the transfer module assembly of the probe of the endoscope of the present invention, as optimized for laparoscopy.

Fig. 5 is an diagrammatic side view of the optical components of the non-disposable focusing ocular of the endoscope of the present invention, as optimized for laparoscopy.

Fig. 6 is a proximal end view in elevation of the prism of the disposable probe of the endoscope of the present invention.

Fig. 7 is a bottom view in plan of the prism.

Fig. 8 is a distal end view in elevation of the prism.

Fig. 9 is a top view in plan of the prism.

Fig. 10 is a view in section of the prism taken along the line 10-10 of Fig. 6.

Fig. 11 is a view in section of a mold suitable for manufacture of the prism.

Fig. 12 is a plot of surface sagitta versus radius specifying the terminology employed to define the aspheric surfaces of lenses in the probe of the endoscope of the present invention.

Fig. 13 is a ray-tracing diagram showing the paths of various light rays through the endoscope of the invention as optimized for laparoscopy, illustrating the positions of intermediate images formed therein.

Fig. 14 is a partially diagrammatic side view comparable to Fig. 4 illustrating a further embodiment of the transfer module of the probe of the endoscope of the present invention, as optimized for laparoscopy.

Fig. 15 is a view comparable to Fig. 4 of the transfer module in an embodiment optimized for arthroscopy.

Fig. 16 is a view comparable to Fig. 5 showing the optical components of the focusing ocular in the embodiment optimized for arthroscopy.

Fig. 17 is a view comparable to Fig. 13 of the endoscope of the invention in the embodiment optimized for arthroscopy.

Fig. 18 is a view comparable to Fig. 5 showing the endoscope in a further embodiment employing an afocal coupler connecting the transfer module to a conventional focusing ocular.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is an exploded view of the principal components of a complete endoscope assembly according to the invention. The disposable probe 10 of the endoscope includes an elongated probe section 12 and a termination 14. The termination 14 comprises a male member 16 received in a recess formed in the body of a focusing ocular 20 of the endoscope. The male member 16 may be releasably coupled to the body of the ocular 20 in generally conventional fashion. Suitable focusing mechanisms for the ocular 20 are well known in the art. The ocular 20 in turn is mated with a video camera 22 or other image forming device in a generally conventional manner well understood by those of skill in the art. As discussed in detail below, the endoscope of the present invention is preferably used in conjunction with a video camera 22 including a so-called "CCD" imaging element and spectral and spatial filter elements.

Fig. 2 is a side view of the complete optical system of the endoscope according to the invention. The external shapes of the termination 14 and ocular 20 are shown in phantom to clarify the relation of these sections of the complete endoscope, but this is not a limitation on the probe of the present invention. The disposable probe 10 comprises an objective group 24 and a transfer module assembly 26. Transfer module assembly 26 comprises three essentially identical relay modules 28, 30 and 32. The relay modules can be multiplied as needed to obtain the

desired total probe length; preferably, an odd number of relay modules is employed to insure that the image is not inverted at the proximal end of probe 10.

As can be seen in Fig. 2, the objective comprises an end window element 34, a prism 36, and three lenses 38, 40 and 42. The structure of objective 24 is discussed in detail below in connection with Fig. 3. Only end window element 34 is glass; prism 36 and lenses 38, 40 and 42 are all molded of plastic, greatly reducing the overall cost of disposable probe 10.

In a first embodiment of the endoscope of the invention optimized for laparoscopy shown in Fig. 2, the three relay modules 28, 30 and 32 making up transfer module assembly 26 each comprise an entry field lens 44, a first plano ended glass rod 45, a first doublet comprising molded plastic elements 52 and 53, a second plano ended glass rod 46, a second doublet comprising molded elements 53 and 52, a third plano ended glass rod 47, and an exit field lens 48. As discussed below in detail, the endoscope of the invention as optimized for arthroscopy is substantially identical in the overall design of its ocular and objective. The transfer module of the endoscope optimized for arthroscopy differs from that of the endoscope optimized for laparoscopy in that the former does not include field lenses. The detailed optical prescriptions of the two embodiments of the endoscope differ accordingly. Full details are found in the accompanying Tables I and II.

Field lenses 44 and 48 used in the endoscope optimized for laparoscopy are of identical optical specification, but are in respectively reversed positions. Similarly, the respective positions of lenses 52 and 53 of the doublets are reversed where they appear in alternating positions along the transfer module assembly. The transfer module assembly 26 is terminated by an optical window 56 at its proximal end. The transfer module assembly 26 of the endoscope as optimized for laparoscopy is described in detail below in connection with Fig. 4, and an alternative embodiment

thereof is shown in Fig. 14. The transfer module of the endoscope optimized for arthroscopy is shown in Fig. 15.

Focusing ocular 20 comprises a window 58 designed to be disposed in close proximity to but not touching window 56. In a preferred embodiment of the endoscope optimized for laparoscopy, ocular 20 comprises a first glass element 60, which is axially movable to focus the image. In the arthroscopic embodiment, a doublet element is moved to focus the endoscope. See Fig. 17. The ocular of both embodiments further includes a doublet comprising glass elements 62 and 64, and further elements 66 and 68. The focusing ocular 20 is described in detail below in connection with Figs. 5 and 16.

Having now briefly identified the components of the disposable endoscope of the invention, a discussion will now be provided of the structure and functions of each. Subsequently the detailed optical specifications of each of the elements in the two specific embodiments mentioned are presented in tabular form. Further possible modifications are then discussed.

As discussed above, the endoscope of the present invention comprises a disposable probe 10, the probe 10 including a distal objective 24 for forming an image and a transfer module assembly 26 for transferring the image from the distal end of the probe to the proximal end of the probe, and a focusing ocular group 20 for presenting this image to a video camera 22 or equivalent device for providing a visible image. The prior art has invariably (so far as known to the present inventor) attempted to provide self-correcting endoscope probes; that is, the prior art has attempted to provide endoscope probes forming an image including no residual aberration to be corrected by the focusing ocular. The prior art suggests that one element of an endoscope probe may be designed to correct optically for aberration introduced by another group of the probe. For example, in Yamashita et al U.S. Patent No. 4,165,917 the astigmatism of the objective is corrected by the relay lens group (i.e. the transfer module), whereby the image

presented to the ocular is fully corrected. However, as mentioned above, the art does not suggest that aberrations introduced by the probe might usefully be corrected by the ocular.

According to an important feature of the present invention, the image provided by the probe is permitted to include certain aberration to be corrected by the focusing ocular. The aberration in the image provided by the probe is sufficiently severe that if the image were not corrected it would be considered unacceptably distorted. Correction by the ocular of residual aberration in the image formed by the probe permits very substantial simplification of the optical design of the disposable probe of the invention, reducing the cost of the probe such that it is cost-effective for disposability after single patient use. In particular, this has enabled placement of substantially all glass elements having curved surfaces in ocular 20, while disposable probe 10 principally includes molded plastic focusing lenses and plano-ended glass rods.

As noted, typically the elements of the focusing ocular are formed of glass using conventional glass polishing techniques; in this case the ocular is too costly for disposability. However, as glass molding technology matures, it may become economically reasonable to mold the glass elements of the ocular, reducing its cost to the extent the ocular may be disposable. Furthermore, with certain design modifications generally within the skill of the art, the ocular could also be made using molded plastic elements, and would thus be cost-effective for single-patient disposable use.

In a further embodiment, the disposable probe may include a disposable coupler for correcting the aberration in the image. The image may then be presented from the coupler to a conventional ocular, that is, as used with prior art non-disposable endoscope probes. This further embodiment is discussed below. Each of these alternatives is within the scope of the invention.

More specifically, relatively large amounts of field curvature, axial chromatic aberration, and lateral chromatic aberration, as well as astigmatism, exist in the image formed by the disposable probe 10 of the invention, but the image is nearly completely corrected with respect to spherical aberration and coma. The ocular 20 comprises optical glass elements eliminating the residual aberration in the image provided by the disposable probe. Of course ocular 20 must also correct any optical aberration introduced by its own components. The ocular 20 also includes an axially movable glass element for focusing the endoscope of the invention. Provision of the focusing mechanism in the non-disposable ocular rather than in the disposable probe further reduces the cost of the probe. As noted, the overall configuration of the objective and ocular are very similar in both laparoscopic and arthroscopic embodiments, while the transfer modules differ somewhat more significantly.

Referring now to the individual elements of the endoscope of the invention, the individual optical surfaces through which rays from the object pass and other significant optical features are identified herein and in the accompanying drawings and claims, and are specified in the Tables below, by individually numbered optical surfaces, reading from $S_1$ at the distal tip of the probe to the imaging surface of a CCD sensor comprised by video camera 22. Table I refers to the embodiment of the endoscope of the invention optimized for laparoscopy; Table II refers to the embodiment of the endoscope of the invention optimized for endoscopy. Although as shown in the Tables the optical prescriptions of the differing embodiments of the invention differ somewhat, common reference numerals are used for simplicity where possible. Thus, the physical description following of the endoscope of the invention applies essentially equally to both embodiments, except where noted, although the surface numbers given in the Tables with respect to the two embodiments do not directly correspond to one another.

The embodiment of the invention optimized for laparoscopy is discussed first, with reference to Figs. 2-5, 13, 14, and Table I. A discussion of the embodiment optimized for arthroscopy follows, with reference to Figs. 15 - 17 and Table II. A description of a further embodiment employing an afocal coupler is then described with reference to Fig. 18.

The objective 24 comprises a glass window element 34 at the distal tip of the probe, a prism 36, and three optical elements 38, 40, and 42. The glass window element 34 at the tip of the probe provides satisfactory bio-environmental compatibility. Window element 34 has a planar distal surface $S_1$ and a concave lens surface $S_2$ (see Fig. 3) formed on its inner planar surface for broadening the field of view of the probe. The plano-concave window element 34 is formed of a high index of refraction crown glass providing improved control of the lateral chromatic aberration of the objective. Lateral chromatic aberration introduced by window 34 is corrected by the use of a high index flint-like optical plastic for the prism 36, which also corrects lateral chromatic aberration introduced by the two elements 38 and 40 immediately following the prism.

An equivalent front window element 34 might be manufactured conveniently with an aspheric inner surface. This can be accomplished by fabricating a glass substrate having a planar outer surface and a spherical concave inner surface. A quantity of suitable optical plastic or resin material is disposed in the concavity, and pressed against an aspheric mold member under suitable conditions of temperature and pressure to mold the aspheric surface. Such processes are generally known to the art.

The prism 36 of the present invention is a unitary member injection molded of a moderately high refractive index plastic such as NAS (an acrylic/polystyrene copolymer). As noted above, as glass molding technology matures, it may become feasible to mold the prism of glass. The prism has two internal reflecting surfaces $S_4$ and $S_6$ so that the image retains its proper "hand".

Prism 36 is generally cylindrical, having a distal planar surface $S_3$ juxtaposed to glass window element 34 at the tip of probe 10. Surface $S_3$ and window element 34 are inclined at an angle to the optical axis of the prism, and are normal to the center of the field of view of the probe. The proximal planar surface $S_7$ of prism 36 is orthogonal to the optical axis of the probe. In this way, both the entry and exit surfaces of prism 36 are perpendicular to rays along the optical axis to control optical aberration.

Three molded plastic lenses 38, 40, and 42 follow the prism in objective group 24. Lenses 38 and 40 are physically identical, but their relative orientations are reversed. The third lens 42 is unique. The two identical lens elements 38 and 40 each include one aspheric surface (these being identified as surfaces $S_9$ and $S_{10}$ in Fig. 3) and one spherical surface ($S_8$ and $S_{11}$). This arrangement provides improved control of spherical aberration and astigmatism. Aberration control by aspheric surfaces $S_9$ and $S_{10}$ is necessary due to the effective location of the aperture stop ($S_5$) in the center of the fore-oblique prism 36; some rays pass through the two elements 38 and 40 relatively far from the optical axis.

The final element of the objective, lens 42, is also injection molded, from a flint-like optical plastic material. Use of the flint-like material permits this element to compensate for much of the axial and lateral chromatic aberration introduced by the preceding elements. The choice of an uncemented final element 42 permits its front surface $S_{12}$ to be curved independently of element 40, compensating for astigmatism introduced by the preceding elements.

The elements of the objective are spaced from one another by air gaps. Precise control of the lengths of the air gaps may be provided by spacer members (not shown) integrally molded around the peripheries of the optical surfaces. These integral spacers eliminate the need for separate small components, avoiding the cost of their fabrication and assembly. A further spacer 82 is provided

between the third element 42 of the objective and the first lens 44 of transfer module assembly 26. The inner periphery of spacer 82 is the field stop, identified as surface $S_{14}$. The field stop 82 is thus physically located between proximal element 42 of the objective and transfer module assembly 26.

As described above, in a typical endoscope according to the present invention, transfer module assembly 26 may be considered to comprise three substantially identical relay modules 28, 30 and 32. The central relay module 30 of the endoscope of the invention in its "laparoscopic" embodiment is shown in further detail in Fig. 4. The number of relay modules in the transfer module assembly can be extended more or less indefinitely, although odd numbers of relay modules are typically used to preserve image orientation.

The relay modules 28, 30 and 32 each comprise an entry field lens 44, a first glass rod 45, a first doublet comprising lenses 52 and 53, an intermediate glass rod 46, a second doublet comprising lens 53 and 52, a third glass rod 44 and an exit field lens 48. As discussed in detail below in connection with Fig. 13, intermediate aperture planes, that is, images of the aperture stop, are formed within intermediate glass rods 46 of each relay module. Field planes, that is, intermediate images of the object, are formed between exit field lenses 48 and entry field lenses 44 of adjoining relay modules, between objective 24 and transfer module 26, and between transfer module 26 and ocular 20.

Each of the glass rods 45, 46 and 47 of each transfer module assembly is plano-ended, reducing cost. Further, rods 45 - 47 are all of identical length, again reducing cost. The surfaces of rods 45 - 47 and lenses 44, 52, 53, 53, 52 and 48 in each transfer module are identified in the central transfer module 30 in Fig. 4 corresponding to the complete listing of the surfaces of the "laparoscopic" embodiment in Table I below, and as shown in Fig. 13. Thus, the entry surface of the first glass rod 45 of second relay

module 30 is identified as $S_{38}$ in Fig. 4 and in Table I; the corresponding surfaces in the first and third relay modules 28 and 32 are identified as $S_{18}$ and $S_{58}$, as indicated in Table I and Fig. 13.

Relay modules 28, 30 and 32 each further comprise two doublets each including two molded plastic lenses 52 and 53. Lenses 52 and 53 are thus used twice in each relay module, with their orientation with respect to one another in each doublet being reversed according to the respective position of the doublet within the relay module, as shown in Fig. 4. The molded plastic lenses 52 and 53 of each doublet preferably include integrally molded spacers (not shown) defining the air gaps between lenses 52 and 53 and the adjoining glass rods, to further simplify assembly of the probe and reduce its cost.

Ideally, the two elements 52 and 53 of each of the doublets are cemented together to minimize alignment sensitivity and light loss. However, this is not necessarily required; use of air-spaced doublets will further reduce the instrument cost.

As noted, in the laparoscopic embodiment, each relay module further comprises an entry field lens 44 and an exit field lens 48. Lenses 44 and 48 are physically identical, but are disposed in the opposite orientations, as shown. Thus, the entry surface $S_{36}$ of the entry field lens 44 of intermediate relay module 30 exhibits the same curvature as the exit surface $S_{54}$ of exit field lens 48. One surface of each field lens is aspheric, e.g., surface $S_{37}$ of entry field lens 44 and surface $S_{53}$ of exit field lens 48. Aspheric surfaces are used in the field lenses to substantially reduce spherical aberration. Residual field curvature and axial and lateral chromatic aberration are eliminated by the optics of the ocular, as discussed previously.

A principal advantage of the design shown is that the plano-ended glass rods can be manufactured very readily, since no curved glass surfaces need to be polished. In the embodiment shown, all of the plano-ended glass rods are of

identical length, further reducing cost. Furthermore, employing only a limited number of types of molded plastic lenses in the transfer module allows the lenses to be manufactured relatively inexpensively in high quantity by injection molding. However, as the cost of molding glass elements is reduced, it may prove cost-effective to mold the lenses of glass; this alternative is within the scope of the invention.

As indicated in Fig. 4 and as discussed above, first and second intermediate field planes indicated at $S_{35}$ and $S_{55}$ are formed between adjacent relay modules. Comparable input and output field planes indicated at $S_{15}$ and $S_{77}$ in Table I and Fig. 13 are also formed between the objective 24 and transfer module 26, and between the transfer module 26 and the ocular 20. Aperture planes are formed at the center of the intermediate rods 46 of each relay module; the aperture plane at the center of the intermediate relay module 30 is denominated $S_{45}$. The corresponding aperture planes of the first and third relay modules 28 and 32 are listed in Table I and shown in Fig. 13 at $S_{25}$ and $S_{65}$, respectively.

Referring now to Fig. 5, the ocular 20 in the laparoscopic embodiment comprises an axially movable plano-convex focusing element 60 near an intermediate image location denoted by surface $S_{82}$. (As discussed below, in the arthroscopic embodiment, the ocular includes a doublet moved axially to focus the image.) Focusing element 60 bends the telecentric chief ray down toward the aperture of the following elements. The aperture is defined by an aperture stop 61. Ocular 20 also comprises a cemented doublet, including elements 62 and 64, and an air-spaced doublet including elements 66 and 68. The cemented doublet including elements 62 and 64 could also be designed as an air-spaced doublet, but the cemented form is preferred since the manufacturing tolerances thereon are more forgiving. The cemented doublet comprising elements 62 and 64 provides most of the image forming power of the system, and provides

substantial correction of the axial chromatic aberration of the overall system.

The air-spaced doublet comprising elements 66 and 68 uses two glass types to permit correction of most of the lateral chromatic aberration of the overall system. The airspace allows the surfaces of elements 66 and 68 to be separately curved to correct astigmatism introduced by the remainder of the ocular group, and to correct residual astigmatism and field curvature in the image received from the disposable probe 10.

As discussed above, ocular 20 provides focus adjustment for changes in object distance by axial displacement of the focusing element 60. Focus adjustment is effective for object distances from infinity to the outer surface of objective window 34 with very little loss in image quality. The use of weakly powered elements for focusing makes both image location and quality reasonably insensitive to radial displacement of the element during focus adjustment. Field curvature remaining in the image received from the transfer module assembly 26 is corrected by concave surface $S_{88}$ formed on element 68 of the ocular 20.

Fig. 5 also shows for completeness three plano-surfaced window elements 70, 71 and 72 provided as part of the video camera 22 with which the endoscope of the invention is preferably utilized. Window 72 protects the CCD imaging element of video camera 22. Window 71 is an infrared filter, that is, a spectral filter removing infrared components from the imaged light. Substantially all CCD video cameras sold for endoscopic imaging purposes include suitable elements 71 and 72. The third window element shown is a spatial filter 70 provided in certain video cameras sold for endoscopic imaging purposes by the Sony Corporation of Japan. Such spatial filters prevent aliasing of the image formed by the CCD element, and their use is accordingly preferred. However, the endoscope of the invention is useful with CCD video cameras not including such spatial filters 70; accordingly, the detailed optical

specifications given below for the endoscope of the invention need not vary in dependence on the presence or absence of spatial filter 70.

Figs. 6 - 10 provide details of the prism 36. Window element 34 is also shown in phantom in Fig. 10 for clarity. The prism is essentially identical in both embodiments of the invention; the slightly differing optical prescriptions of the 30° prism of the particular laparoscopic embodiment and of the 25° prism of the particular arthroscopic embodiment disclosed in detail herein are found in Tables I and II, respectively.

Prism 36 is a generally cylindrical solid member, having a first recess 90 formed in its "top" (in the orientation shown) and a second recess 92 formed in its "lower" surface. The innermost surface $S_6$ of recess 90 is planar, as is the innermost surface $S_4$ of recess 92. Rays entering prism 36 at a distal inclined surface $S_3$ reflect in sequence from surfaces $S_4$ and $S_6$ and exit prism 36 through proximal planar end surface $S_7$. Surface $S_5$ corresponds to an intermediate image of the aperture stop 61 located between the reflective surfaces $S_4$ and $S_6$, whereby the aperture stop 61 is effectively located within prism 36.

Line 100 indicates the axis of the field of view. Lines 101 - 103 indicate the path in the prism of the ray entering the prism along axis 100. The ray exits the prism along line 103, that is, along the optical axis of the probe. The surface $S_3$ at which prism 36 is juxtaposed to window 34 at the tip of the disposable probe of the endoscope according to the invention is normal to the axis of the field of view of the endoscope defined by axis 100. Rays from the center of the field of view are thus normal to the oblique entry surface $S_3$ of prism 36 and exit the prism orthogonal to the proximal exit surface $S_6$, in order to reduce aberration.

The detailed specifications of the prism vary with the desired viewing angle, that is, with the desired angle made between the axis 100 of the field of view and the optical

axis 103 of the probe. In the embodiment detailed in Table I this angle is 30°. Accordingly, angle A, between the distal surface $S_3$ and the optical axis, is 60°. Angle B, the angle between the first reflecting surface $S_4$ and the optical axis, is 19°, and angle C, between the second reflecting surface $S_6$ and the rear face of the prism 36, is 56°. Surface $S_6$ thus is oriented at an angle of 34° to the optical axis. Table II provides corresponding details for a prism providing a 25° viewing angle.

It is within the scope of the invention to provide prisms having different viewing angles which may exceed 90°, providing a retrograde field of view. Further, it is also within the scope of the invention to replace the prism 36 shown by a single cylindrical element in order to form an image of a field of view directly centered on the optical axis of the probe. No modification to the optical design of the remainder of the objective, the transfer module assembly, or the ocular is required to do so.

It will be apparent by study of Figs. 7 and 9 that longitudinal lines bisecting the reflecting surfaces $S_4$ and $S_6$ intersect the optical axis, i.e., that the reflecting surfaces are longitudinally centered on the optical axis. Similarly, transverse lines 104 and 106 on each of the reflecting surfaces $S_6$ and $S_4$, respectively, orthogonal to these longitudinal lines are parallel to one another and accordingly orthogonal to the optical axis.

In both 30° and 25° embodiments of the prism of the invention as defined in Tables I and II, it is possible to select the index of refraction of the material of the prism 36 with respect to the angle of incidence of the rays on the second reflecting surface $S_6$ such that reflection of the rays takes place at surface $S_6$ due to total internal reflection within the prism, so that no reflective coating is required on surface $S_6$, simplifying the manufacture of the prism.

The preferred material of the prism is injection molded plastic. A suitable material known as NAS is a copolymer of

70% polystyrene and 30% acrylic. A particularly suitable choice is NAS30 material, sold by Polysar, Inc.

A reflective coating 73, e.g., of aluminum, is required on surface $S_4$. Preferably the end surfaces $S_3$ and $S_7$ are provided with an anti-reflection coating to insure maximum transmission of the light being gathered. The second reflective surface $S_6$ should be left optically clear for total internal reflection.

In some embodiments of the invention it may be desired to provide an opaque baffle 74 within the recess 90 to prevent stray light from entering the optical path. The lower extremity of baffle 74 must be spaced from the reflecting surface $S_6$.

As shown in Fig. 10 and also in Fig. 3, a concave lens surface $S_2$ is formed in the glass window element 34 to which the front surface $S_3$ of the prism 36 is juxtaposed. This concave lens surface $S_2$ is centered about the axis of the field of view 100. The function of this concave lens surface $S_2$ is to collect light from a broad field of view.

In order that light gathered by lens surface $S_2$ can be efficiently transmitted by the prism, it is important that a region 108 (Fig. 9) on surface $S_3$ remain optically clear. Similarly, the rear surface $S_7$ (Fig. 6) of the prism should have a clear aperture 110. A central section 112 (Fig. 7) of first reflecting surface $S_4$ similarly must be clear prior to application of reflective coating 73, and the second reflecting surface $S_5$ (Fig. 9) should include a rectangular clear aperture 114.

Preferably prism 36 is manufactured by injection molding. A suitable mold 320 is shown in Fig. 11. Mold 320 includes a mold cavity 312 generally conforming to the cylindrical outline of the prism, having one end orthogonal to the cylindrical axis and one oblique end, conforming to the surfaces $S_7$ and $S_3$ of the prism, respectively. The mold 320 includes two opposed slide members 324 and 326 to be controllably inserted into and withdrawn from mold cavity 312. Slide members 324 and 326 have distal tips

corresponding in shape to the desired recesses 90 and 92 in the prism. Manufacture of the prism simply involves the steps of inserting slide members 324 and 326 into the mold cavity, injecting the appropriate Polysar NAS30 acrylic material, allowing it to cool and harden, withdrawing slide members 324 and 326 from the mold cavity 312 to the positions shown in Fig. 11, and withdrawing the hardened prism precursor 328 from the mold cavity. The first reflecting surface $S_4$ is then coated with suitable reflective material, and the remaining critical surfaces are coated with a suitable anti-reflection coating.

As indicated above, Table I below details each of the critical optical parameters of the laparoscopic embodiment of the invention, and Table II provides similar details of the arthroscopic embodiment.

In the following, optical components having flat or spherical surfaces are specified by definition of the radii of their optical surfaces, the index of refraction and the dispersion of their materials, and by their thickness along the optical axis. Aspheric surfaces are defined in this specification and the appended claims by the values needed to complete the following equation:

$$z = \frac{ch^2}{1+[1-(1+k)c^2h^2]^{1/2}} + Ah^4 + Bh^6 + Ch^8 + Dh^{10}$$

wherein:

A, B, C, and D are constants;

k is the conic constant of the surface;

c is the basic curvature of the surface, such that c = 1/R in the case where k = A = B = C = D = 0, and the equation defines a spherical surface of radius R; and

z is the sagitta, that is, the distance between a plane tangent to the aspheric surface at the optical axis and all points P (h,z) on the surface a radial distance h measured orthogonal to the optical axis.

Fig. 12 explains the values of the variables z and h appearing in this equation. Points P (h,z) define the aspheric surface, appearing in two dimensions as a parabola.

All points P (h,z) lie on a circle of radius h (or "semi-diameter", in optical parlance) on the aspheric surface, where z is the sagitta, that is, is the length of a normal from the plane tangent to the spherical surface at the optical axis to the circle.

This method of defining an aspheric surface is an industry standard and familiar to those skilled in the art.

Accordingly, the aspheric surfaces of the exemplary implementation of the optical system of the endoscope of the invention are adequately described in the Tables by the listed values for A, B, C, D, c, and k. The curvature c is specified by giving the inverse value of the base radius R. Similarly, in the claims appended to this specification, aspheric surfaces are defined by provision of these six values, and reference is to be made to the equation above for their definition.

As is conventional in the optics art, the spherical elements of an exemplary implementation of the endoscope of the invention are specified in the Tables by the radii of their surfaces (a negative sign indicating the center of the surface is disposed more closely to the distal tip of the probe than is the surface, as is conventional), the thickness of the element, and the index of refraction and dispersion of the material. The surfaces $S_1$ - $S_{93}$ appearing in Table I are specifically identified in Figs. 3 - 10 and 13, while the surfaces $S_1$ - $S_{71}$ of Table II are identified in Figs. 15 - 17. The Tables further include specification of suitable materials for each of the elements. (Throughout this specification and the appended claims, all values for indices of refraction refer to the index of refraction measured with respect to the "D-line" in the sodium spectrum, as is conventional.)

Thus, for example, window 34 at the tip of the probe is shown by Table I to be formed of type LAF2 optical glass having index of refraction 1.744 and dispersion 44.72. Its outer surface $S_1$ is planar (i.e., of infinite radius) and its inner surface $S_2$ is concave and of 2.352 mm radius. The

central thickness of window 34 measured along the center of the field of view is 1.492 mm. Surface $S_2$ is centered on axis 100, the center of the field of view of the system. Axis 100 is at 30° to the optical axis of the probe in this implementation of the invention. The outer planar surface $S_1$ of the glass window 34 is orthogonal to axis 100.

The next element in objective section 24 of probe 10 is the prism, as discussed above in detail. As there indicated, the prism is molded of Polysar NAS30 plastic, having a index of refraction of 1.564 and dispersion of 35.0. The front surface $S_3$ at which prism 36 is juxtaposed to window 34 is inclined at an angle of 30° to the optical axis; its first reflective surface $S_4$, having a reflective coating 73 thereon, is inclined at angle B of 19° to the optical axis. The inclination of surface $S_4$ is therefore specified in Table I by the angle of 19°, angle B, between $S_4$ and the optical axis. Second reflecting surface $S_6$ of prism 36 is inclined at 34° to the optical axis; this relation is specified in Table I by the 56° angle, angle C, between $S_6$ and the proximal planar end $S_7$ of the prism 36. As noted above, surface $S_5$ in Table I does not correspond to a physical surface, but refers to the effective location of the aperture stop which is imaged within prism 36.

The remaining entries in Table I follow the format just discussed. Table I also provides all relevant airspaces and other information not specifically given above. Table I thus provides a complete optical prescription for a disposable endoscope; from this information, one of skill in the art would have no difficulty in constructing an endoscope according to the "laparoscopic" embodiment of the present invention. The focusing element 60 is provided with axial motion of at least about 3.0mm to enable focusing of the endoscope from the front surface of window 34 to infinity. The endoscope thus defined has a field of view approximately 80° wide centered on an axis 30° from the optical axis of the probe, and a typical working distance of 75mm in air.

TABLE I

| $S_n$ | Radius (mm) or Aspheric Values | Thickness (mm) | Medium | I.R. | Disp. | Element |
|---|---|---|---|---|---|---|
| OBJ | INFINITY | 75.000000 | | | | |
| 1 | INFINITY | 1.492000 | LAF2-SCHOTT | 1.74400 | 44.72 | WINDOW 34 |
| 2 | 2.35200 | 0.540000 | | | | |
| 3 | INFINITY | 3.175000 | NAS30 | 1.56400 | 35.00 | PRISM 36 |
| 4 | INFINITY (-19.00°) | -0.635000 | REFL | | | |
| 5 | INFINITY | -2.159000 | | | | |
| 6 | INFINITY (+56.00°) | 3.556000 | REFL | | | |
| 7 | INFINITY | 0.501377 | | | | |
| 8 | 6.93464 | 3.429000 | V920 | 1.49200 | 57.40 | LENS 38 |
| 9 | c = -8.54871 | 0.655172 | | | | |
| | k = -3.846356 | | | | | |
| | A = 0.178981E-03 | | | | | |
| | B = 0.490596E-04 | | | | | |
| | C = D = 0 | | | | | |
| 10 | c = 8.54871 | 3.429000 | V920 | 1.49200 | 57.40 | LENS 40 |
| | k = -3.846356 | | | | | |
| | A = -.178981E-03 | | | | | |
| | B = -.490596E-04 | | | | | |
| | C = D = 0 | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | -6.93464 | 0.620078 | | | | |
| 12 | -22.07181 | 2.032000 | NAS30 | 1.56400 | 35.00 | LENS 42 |
| 13 | 22.07181 | 1.007701 | | | | |
| 14 | INFINITY | 3.636480 | | | | APERTURE STOP |
| 15 | INFINITY | 1.750000 | | | | INPUT FIELD PLANE |
| 16 | -5.93473 | 3.556000 | V920 | 1.49200 | 57.40 | INPUT FIELD LENS 44 |
| 17 | c = -5.69019 | 0.179140 | | | | |
| | k = -3.628766 | | | | | |
| | A = -.241315E-02 | | | | | |
| | B = -.691773E-05 | | | | | |
| | C = D = 0 | | | | | |
| 18 | INFINITY | 30.4800000 | SK5-SCHOTT | 1.58913 | 61.27 | ROD 45 |
| 19 | INFINITY | 0.363713 | | | | |
| 20 | 21.52290 | 3.048000 | NAS30 | 1.56400 | 35.00 | LENS 52 |
| 21 | 7.82682 | 0.000000 | | | | |
| 22 | 7.82682 | 3.556000 | V920 | 1.49200 | 57.40 | LENS 53 |
| 23 | -22.60502 | 0.370663 | | | | |
| 24 | INFINITY | 15.240000 | SK5-SCHOTT | 1.58913 | 61.27 | ROD 46 |
| 25 | INFINITY | 15.240000 | SK5-SCHOTT | 1.58913 | 61.27 | FIRST APERTURE PLANE |
| 26 | INFINITY | 0.370663 | | | | |
| 27 | 22.60502 | 3.556000 | V920 | 1.49200 | 57.40 | LENS 53 |
| 28 | -7.82682 | 0.000000 | | | | |
| 29 | -7.82682 | 3.048000 | NAS30 | 1.56400 | 35.00 | LENS 52 |
| 30 | -21.52290 | 0.363713 | | | | |
| 31 | INFINITY | 30.480000 | SK5-SCHOTT | 1.58913 | 61.27 | ROD 47 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 32 | INFINITY | 0.179140 | | | | |
| 33 | c = 5.69019 | 3.556000 | V920 | 1.49200 | 57.40 | EXIT FIELD LENS 48 |
| | k = -3.628766 | | | | | |
| | A = 0.241315E-02 | | | | | |
| | B = 0.691773E-05 | | | | | |
| | C = D = 0 | | | | | |
| 34 | 5.93473 | 1.054699 | | | | |
| 35 | INFINITY | 1.054700 | | | | FIRST FIELD PLANE |
| 36 | -5.93473 | 3.556000 | V920 | 1.49200 | 57.40 | ENTRY FIELD LENS 44 |
| 37 | c = -5.69019 | 0.179140 | | | | |
| | k = -3.628766 | | | | | |
| | A = -.241315E-02 | | | | | |
| | B = -.691773E-05 | | | | | |
| | C = D = 0 | | | | | |
| 38 | INFINITY | 30.480000 | SK5-SCHOTT | 1.58913 | 61.27 | ROD 45 |
| 39 | INFINITY | 0.363713 | | | | |
| 40 | 21.52290 | 3.048000 | NAS30 | 1.56400 | 35.00 | LENS 52 |
| 41 | 7.82682 | 0.000000 | | | | |
| 42 | 7.82682 | 3.556000 | V920 | 1.49200 | 57.40 | LENS 53 |
| 43 | -22.60503 | 0.370663 | | | | |
| 44 | INFINITY | 15.240000 | SK5-SCHOTT | 1.58913 | 61.27 | ROD 46 |
| 45 | INFINITY | 15.240000 | SK5-SCHOTT | 1.58913 | 61.27 | SECOND APERTURE PLANE |
| 46 | INFINITY | 0.370663 | | | | |
| 47 | 22.60503 | 3.556000 | V920 | 1.49200 | 57.40 | LENS 53 |
| 48 | -7.82682 | 0.000000 | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 49 | -7.82682 | 3.048000 | NAS30 | 1.56400 | 35.00 | LENS 52 |
| 50 | -21.52290 | 0.363713 | | | | |
| 51 | INFINITY | 30.480000 | SK5-SCHOTT | 1.58913 | 61.27 | ROD 47 |
| 52 | INFINITY | 0.179140 | | | | |
| 53 | c = 5.69019 | 3.556000 | V920 | 1.49200 | 57.40 | EXIT FIELD LENS 48 |
| | k = -3.628766 | | | | | |
| | A = 0.241315E-02 | | | | | |
| | B = 0.691773E-05 | | | | | |
| | C = D = 0 | | | | | |
| 54 | 5.93473 | 1.054700 | | | | |
| 55 | INFINITY | 1.054700 | | | | SECOND FIELD PLANE |
| 56 | -5.93473 | 3.556000 | V920 | 1.49200 | 57.40 | ENTRY FIELD LENS 44 |
| 57 | c = -5.69019 | 0.179140 | | | | |
| | k = -3.628766 | | | | | |
| | A = -.241315E-02 | | | | | |
| | B = -.691773E-05 | | | | | |
| | C = D = 0 | | | | | |
| 58 | INFINITY | 30.480000 | SK5-SCHOTT | 1.58913 | 61.27 | ROD 45 |
| 59 | INFINITY | 0.363713 | | | | |
| 60 | 21.52290 | 3.048000 | NAS30 | 1.56400 | 35.00 | LENS 52 |
| 61 | 7.82682 | 0.000000 | | | | |
| 62 | 7.82682 | 3.556000 | V920 | 1.49200 | 57.40 | LENS 53 |
| 63 | -22.60503 | 0.370663 | | | | |
| 64 | INFINITY | 15.240000 | SK5-SCHOTT | 1.58913 | 61.27 | ROD 46 |
| 65 | INFINITY | 15.240000 | SK5-SCHOTT | 1.58913 | 61.27 | THIRD APERTURE PLANE |

| | | | | | | |
|---|---|---|---|---|---|---|
| 66 | INFINITY | 0.370663 | | | | |
| 67 | 22.60503 | 3.556000 | V920 | 1.49200 | 57.40 | LENS 53 |
| 68 | -7.82682 | 0.000000 | | | | |
| 69 | -7.82682 | 3.048000 | NAS30 | 1.56400 | 35.00 | LENS 52 |
| 70 | -21.52290 | 0.363713 | | | | |
| 71 | INFINITY | 30.480000 | SK5-SCHOTT | 1.58913 | 61.27 | ROD 47 |
| 72 | INFINITY | 0.179140 | | | | |
| 73 | c = 5.69019 | 3.556000 | V920 | 1.49200 | 57.40 | EXIT FIELD LENS 48 |
| | k = -3.628766 | | | | | |
| | A = 0.241315E-02 | | | | | |
| | B = 0.691773E-05 | | | | | |
| | C = D = 0 | | | | | |
| 74 | 5.93473 | 1.750000 | | | | |
| 75 | INFINITY | 1.778000 | | | | |
| 76 | INFINITY | 1.524000 | BK7-SCHOTT | 1.51680 | 64.17 | WINDOW 56 |
| 77 | INFINITY | 0.254000 | | | | OUTPUT FIELD PLANE |
| 78 | INFINITY | 1.524000 | BK7-SCHOTT | 1.51680 | 64.17 | WINDOW 58 |
| 79 | INFINITY | 5.955617 | | | | |
| 80 | INFINITY | 5.080000 | BK7-SCHOTT | 1.51680 | 64.17 | FOCUSING ELEMENT 60 |
| 81 | -16.65782 | 31.701114 | | | | |
| 82 | INFINITY | 0.000000 | | | | FIELD STOP |
| 83 | 11.15562 | 5.080000 | F1-SCHOTT | 1.62588 | 35.70 | LENS 62 |
| 84 | -6.94199 | 2.032000 | SF4-SCHOTT | 1.75520 | 27.58 | LENS 63 |
| 85 | 33.50506 | 0.508000 | | | | |
| 86 | 5.58277 | 5.080000 | SK5-SCHOTT | 1.58913 | 61.27 | LENS 66 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 87 | INFINITY | 2.903624 | | | | |
| 88 | -3.02007 | 2.032000 | SF11-SCHOTT | 1.78472 | 25.76 | LENS 68 |
| 89 | INFINITY | 12.700000 | | | | |
| 90 | INFINITY | 2.000000 | SILICA-SPECIAL | | | WINDOW 70 |
| 91 | INFINITY | 2.350000 | BK7-SCHOTT | 1.51680 | 64.17 | WINDOW 71 |
| 92 | INFINITY | 1.500000 | SILICA-SPECIAL | | | WINDOW 72 |
| 93 | INFINITY | 0.000000 | | | | |
| IMG | INFINITY | 0.000000 | | | | IMAGE PLANE |

Fig. 13 is a complete ray-tracing diagram of the endoscope of the invention in its laparoscopic embodiment showing the respective paths of light rays from various portions of its field of view FOV to the imaging chip at $S_{93}$. Fig. 13 includes complete identification of the surfaces $S_1$ - $S_{93}$ defined by Table I. Light collected from the field of view FOV is formed into an image by objective 24, and the image is reformed at four intermediate field planes, as indicated. The field planes are identified in Fig. 13 and in Table I by surfaces $S_{15}$, $S_{35}$, $S_{55}$, and $S_{77}$, as follows: The input field plane $S_{15}$ is between the objective 24 and input relay module assembly 28, as shown; the first and second intermediate field planes $S_{35}$ and $S_{55}$ are between relay modules 28 and 30, and 30 and 32, respectively; and the output field plane $S_{77}$ is between transfer module assembly 26 and the ocular 20. Fig. 13 also shows the locations of three aperture planes, $S_{25}$, $S_{45}$, and $S_{65}$, corresponding to images of aperture stop 61; a further image of the aperture stop 61 appears at $S_5$, within the prism 34.

By comparison, in the "arthroscopic" embodiment of the invention discussed below, and detailed in Figs. 15 - 17 and Table II, no field lenses are employed. Instead, the transfer module simply comprises a number of molded plastic doublets spaced by plano glass rods. Accordingly, intermediate images are formed within continuous glass rods of the transfer module assembly, rather than between the surfaces of optical elements, as in the "laparoscopic" design. Forming the images within the rods eliminates the effect of any surface imperfections on the ultimate image. On the other hand, formation of the field planes between optical elements, that is, between the field lenses, is required to meet the goals of improved resolution and uniformity of illumination of the embodiment of the present invention in which it is optimized for laparoscopic use.

Fig. 14 shows an alternative embodiment of a relay module 30' of the transfer module for the laparoscopic embodiment, in which the intermediate field planes $S_{35}$ and $S_{55}$

between adjacent relay modules are located within optical elements 72. It will be appreciated from comparison of Figs. 13 and 14 that the overall configuration of the transfer module of Fig. 14 is substantially as discussed above; that is, the transfer module of Fig. 14 again comprises a number of essentially identical relay modules (one complete relay module being shown in Fig. 14), each comprising an entry field lens, a glass rod, a doublet, a second glass rod, a second doublet oriented opposite the first, a third glass rod, and a exit field lens. However, in the Fig. 14 embodiment, the exit and entry field lenses between adjacent relay modules are combined as a single integral element 72. The detailed optical prescription of the endoscope of the invention accordingly varies somewhat.

In the Fig. 4 embodiment, the distances from the field plane to the adjacent lens surfaces must be large enough to prevent any defects on the surfaces or dust particles from appearing in the final image. By combining the entry and exit field lenses as a unitary element 72, as in the embodiment of Fig. 14, this constraint is eliminated; however, the unitary molded elements 72 must be free of contaminants, inclusions or flow lines since the field plane will be located within the element. Further, the transfer module of Fig. 14 requires tooling for the additional unitary field lenses 72, as separate field lenses are still required at either end of transfer module assembly 26.

Figs. 15 - 17 illustrate the "arthroscopic" embodiment of the endoscope according to the present invention. The objective 24 is essentially unchanged with respect to the laparoscopic embodiment of the invention; a specific optical prescription for the objective 24 is given in Table II. The transfer module assembly in this embodiment is shown in further detail in Fig. 15. The transfer module assembly 126 may again be considered to comprise three substantially identical relay modules 128, 130 and 132. Again, the number of relay modules in the transfer module assembly can be extended more or less indefinitely, although odd numbers of

relay modules are typically used to preserve image orientation.

The relay modules 128, 130, and 132 each comprise an entry glass rod, a first doublet, an intermediate glass rod, a second doublet, and an exit rod. The exit rod of one relay module and the entry rod of the succeeding rod are preferably configured as a single rod, as shown. As discussed in detail below in connection with Fig. 17, intermediate images are formed within the glass rods extending between the relay modules. By thus forming the intermediate images within the rods, rather than at their surfaces or in air gaps between the rods, the possibility is eliminated that a scratch or other defect on a rod end surface might interfere with formation of a suitable visible image.

The transfer module assembly 126 may also usefully be considered to comprise a number of relay subgroups 133, each comprising a doublet and an intermediate rod, juxtaposed to one another to make up the bulk of the length of the transfer module assembly. As thus defined, two relay subgroups 133 make up a relay module; the complete transfer module assembly 126 shown in Fig. 15 is made up of five identical subgroups 133, a relatively short glass entry rod 144, and an exit subgroup including a sixth identical doublet and a relatively short exit glass rod 150.

Each of the glass rods 144, 145, 146, 147, 148, 149, and 150 of the transfer module assembly is plano-ended, reducing cost. Further, rods 145 - 149 are of identical length, again reducing cost. The surfaces of rods 144 - 150 are identified in Fig. 15 corresponding to the listings of the rods in Table II below. Thus, the entry surface of the first glass rod 144 of the relay module 128 is identified as $S_{14}$.

The relay modules 128, 130 and 132 each further comprise two doublets each including two molded plastic lenses 152 and 153. Lenses 152 and 153 are thus used twice in each relay module, with their orientation with respect to

one another in each doublet being reversed according to the respective position of the doublet within the relay module, as shown in Fig. 15. The molded plastic lenses 152 and 153 of each doublet preferably include integrally molded spacers (not shown) defining the air gaps between lenses 152 and 153 and the adjoining glass rods, to further simplify assembly of the probe and reduce its cost.

One surface of element 153 of each of the doublets is aspheric, e.g., surface $S_{19}$ of the first occurring element 153 and surface $S_{22}$ of the second occurring element 153. Aspheric surfaces are used in each element 153 to substantially reduce the spherical aberration. Residual field curvature and axial and lateral chromatic aberration are eliminated by the optics of the ocular, as discussed previously.

Ideally, the two elements 152 and 153 of each of the doublets are cemented together to minimize alignment sensitivity and light loss. However, this is not necessarily required; use of air-spaced doublets will further reduce the instrument cost.

An alternative to the use of an aspheric surface on one of the two elements 152 and 153 of the doublets of the transfer module assembly is to replace each of the doublets with a three-element system in which aspheric surfaces can be avoided. As lenses having aspheric surfaces cost no more to mold than spherical lenses, the embodiment shown is preferred.

The principal advantage of the design shown is that the plano-ended glass rods can be manufactured very readily, since no curved glass surfaces need to be polished. Employing only two types of molded plastic lens allows the lenses to be manufactured relatively inexpensively in high quantity by injection molding. As noted above, the lenses 152 and 153 might equivalently be molded of glass rather than plastic.

As stated above, seven plano-ended glass rods 144, 145, 146, 147, 148, 149 and 150 are used in the exemplary

transfer module assembly shown in Figs. 15 - 17. Rods 145, 146, 147, 148, and 149 are identical and their length is kept to a minimum to reduce the chance of breakage, a critical issue in arthroscopic and similar applications where physical stress on the device may be substantial. Rods 144 and 150 are of different lengths in order to accommodate the objective and the ocular window geometries. The chance of breakage is further reduced by provision of plastic spacers (not shown) integrally molded on the end of the intervening lenses 152 and 153, since these spacers absorb much of the compressive stress encountered upon bending of the probe of an endoscope. Prior art designs employing metal spacers between glass lenses force the compressive stresses to be absorbed by the fragile glass components. Alternative embodiments of this invention reduce the rod lengths to further minimize the chance of breakage by dividing rods 145, 146, 147, 148 and 149 into two shorter identical rods with an intervening plastic spacer.

Referring now to Fig. 16, the optical design of the ocular 120 in the arthroscopic embodiment comprises an axially movable cemented focusing doublet comprising elements 159 and 160 near an intermediate image location denoted by object surface $S_{56}$. Focusing doublet 159, 160 bends the telecentric chief ray down toward the aperture of the following elements. Doublet 159, 160 also provides correction of lateral chromatic aberration. The ocular 120 also comprises a second cemented doublet, comprising elements 162 and 164, and a third air-spaced doublet comprising elements 166 and 168. The second cemented doublet comprising elements 162 and 164 could also be designed as an air-spaced doublet, but the cemented form is preferred since the manufacturing tolerances thereon are more forgiving. The second cemented doublet comprising elements 162 and 164 provides most of the image forming power of the system, and provides substantial correction of the axial chromatic aberration of the overall system.

The air-spaced doublet comprising elements 166 and 168 uses two glass types to permit correction of most of the lateral chromatic aberration of the overall system. The airspace allows the juxtaposed surfaces $S_{65}$ and $S_{66}$ of elements 166 and 168 to be strongly curved to correct astigmatism introduced by the remainder of the ocular group and to correct residual astigmatism and field curvature in the image received from the disposable probe.

As discussed above, the ocular 120 provides focus adjustment for changes in object distance by axial displacement of the focusing doublet 159, 160. Focus adjustment is effective for object distances from infinity to the outer surface of the objective window 134 with very little loss in image quality. The use of weakly powered elements for focusing makes both image location and quality reasonably insensitive to radial displacement of the element during focus adjustment. Field curvature remaining in the image received from the transfer module assembly 126 is corrected by convex surface $S_{66}$ formed on element 168 of the ocular 120.

Fig. 16 also shows for completeness three plano-surfaced window elements 70, 71 and 72 provided as part of the video camera 22 with which the endoscope of the invention is preferably utilized. These elements are as discussed above in connection with Fig. 5.

Fig. 17 is a complete ray-tracing diagram of the endoscope of the invention in its "arthroscopic" embodiment, showing the respective paths through the endoscope of light rays from various portions of its field of view FOV. Light collected from the field of view FOV is formed into an image by objective 24, and the image is reformed at four intermediate image locations IL. The first intermediate image location IL is between the objective 24 and the transfer module assembly 126, as shown; the second and third intermediate image locations are between the relay modules 128 and 130, and 130 and 132, respectively; and the fourth intermediate image location is between the transfer module

assembly and the ocular 120. As noted, by forming the second and third intermediate images within continuous glass rods 146 and 148 of the transfer module assembly, rather than at the surfaces of optical elements, the effect of any surface imperfections on the ultimate image is eliminated. Fig. 17 also shows the aperture stop 161; images of the aperture stop appear at locations AS within the prism 34 and at intermediate points within each relay module.

Table II below provides a complete optical prescription of the endoscope of the invention in the "arthroscopic" embodiment. Figs. 15 - 17 collectively identify each of the numbered surfaces referred to in Table II.

TABLE II

| $S_n$ | Radius (mm) or Aspheric Values | Thickness (mm) | Medium | I.R. | Disp. | Element |
|---|---|---|---|---|---|---|
| 1 | INFINITY | 0.762000 | LAF2 | 1.74400 | 44.72 | WINDOW 34 |
| 2 | 1.17650 | 0.270000 | AIR | | | |
| 3 | INFINITY | 1.651000 | NAS30 | 1.56400 | 35.00 | PRISM 36 |
| 4 | INFINITY (−43.50°) | 1.524000 | REFL (NAS30) | | | |
| 5 | INFINITY (+56.00°) | 1.778000 | REFL (NAS30) | | | |
| 6 | INFINITY | 0.127000 | AIR | | | |
| 7 | 3.30200 | 2.286000 | PMMA | 1.49200 | 57.40 | LENS 38 |
| 8 | c = −0.249431 | 0.356564 | AIR | | | |
| | k = −1.026659 | | | | | |
| | A = 0.491000E-02 | | | | | |
| | B = 0.133746E-02 | | | | | |
| | C = D = 0.0 | | | | | |
| 9 | c = 0.249431 | 2.286000 | PMMA | 1.49200 | 57.40 | LENS 40 |
| | k = −1.026659 | | | | | |
| | A = −0.491000E-02 | | | | | |
| | B = −0.133746E-02 | | | | | |
| | C = D = 0.0 | | | | | |
| 10 | −3.30200 | 0.241087 | AIR | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | -7.12576 | 1.651000 | NAS30 | 1.56400 | 35.00 | LENS 42 |
| 12 | 4.94207 | 1.674264 | AIR | | | |
| 13 | INFINITY | 1.016000 | AIR | | | |
| 14 | INFINITY | 12.700000 | BASF2 | 1.66446 | 35.83 | ROD 144 |
| 15 | INFINITY | 0.254000 | AIR | | | |
| 16 | 9.23300 | 1.778000 | NAS30 | 1.56400 | 35.00 | LENS 152 |
| 17 | 4.33469 | 0.000000 | CEMENT | 1.56000 | 44.00 | |
| 18 | 4.33469 | 2.286000 | PMMA | 1.49200 | 57.40 | LENS 153 |
| 19 | c = -0.121238 | 0.254000 | AIR | | | |
| | k = -1.317139 | | | | | |
| | A = -0.269762E-04 | | | | | |
| | B = 0.681709E-04 | | | | | |
| | C = D = 0.0 | | | | | |
| 20 | INFINITY | 28.575000 | BASF2 | 1.66446 | 35.83 | |
| 21 | INFINITY | 0.254000 | AIR | | | |
| 22 | c = 0.121238 | 2.286000 | PMMA | 1.49200 | 57.40 | |
| | k = -1.317139 | | | | | |
| | A = 0.269762E-04 | | | | | |
| | B = -0.681709E-04 | | | | | |
| | C = D = 0.0 | | | | | |
| 23 | -4.33469 | 0.000000 | CEMENT | 1.56000 | 44.00 | |
| 24 | -4.33469 | 1.778000 | NAS30 | 1.56400 | 35.00 | |
| 25 | -9.23300 | 0.254000 | AIR | 1.66446 | 35.83 | LENS 152 |
| 26 | INFINITY | 28.575000 | BASF2 | | | |
| 27 | INFINITY | 0.254000 | AIR | | | ROD 146 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 28 | 9.23300 | 1.778000 | NAS30 | 1.56400 | 35.00 | LENS 152 |
| 29 | 4.33469 | 0.000000 | CEMENT | 1.56000 | 44.00 | |
| 30 | 4.33469 | 2.286000 | PMMA | 1.49200 | 57.40 | LENS 153 |
| 31 | c = -0.121238 | 0.254000 | AIR | | | |
| | k = -1.317139 | | | | | |
| | A = -0.269762E-04 | | | | | |
| | B = 0.681709E-04 | | | | | |
| | C = D = 0.0 | | | | | |
| 32 | INFINITY | 28.575000 | BASF2 | 1.66446 | 35.83 | ROD 147 |
| 33 | INFINITY | 0.254000 | AIR | | | |
| 34 | c = 0.121238 | 2.286000 | PMMA | 1.49200 | 57.40 | LENS 153 |
| | k = -1.317139 | | | | | |
| | A = 0.269762E-04 | | | | | |
| | B = -0.681709E-04 | | | | | |
| | C = D = 0.0 | | | | | |
| 35 | -4.33469 | 0.000000 | CEMENT | 1.56000 | 44.00 | |
| 36 | -4.33469 | 1.778000 | NAS30 | 1.56400 | 35.00 | LENS 152 |
| 37 | -9.23300 | 0.254000 | AIR | | | |
| 38 | INFINITY | 28.575000 | BASF2 | 1.66446 | 35.83 | ROD 148 |
| 39 | INFINITY | 0.254000 | AIR | | | |
| 40 | 9.23300 | 1.778000 | NAS30 | 1.56400 | 35.00 | LENS 152 |
| 41 | 4.33469 | 0.000000 | CEMENT | 1.56000 | 44.00 | |
| 42 | 4.33469 | 2.286000 | PMMA | 1.49200 | 57.40 | LENS 153 |
| 43 | c = -0.121238 | 0.254000 | AIR | | | |
| | k = -1.317139 | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | A = -0.269762E-04 | | | | | |
| | B = 0.681709E-04 | | | | | |
| | C = D = 0.0 | | | | | |
| 44 | INFINITY | 28.575000 | BASF2 | 1.66446 | 35.83 | ROD 149 |
| 45 | INFINITY | 0.254000 | AIR | | | |
| 46 | c = 0.121238 | 2.286000 | PMMA | 1.49200 | 57.40 | LENS 153 |
| | k = -1.317139 | | | | | |
| | A = 0.269762E-04 | | | | | |
| | B = -0.681709E-04 | | | | | |
| | C = D = 0.0 | | | | | |
| 47 | -4.33469 | 0.000000 | CEMENT | 1.56000 | 44.00 | |
| 48 | -4.33469 | 1.778000 | NAS30 | 1.56400 | 35.00 | LENS 152 |
| 49 | -9.23300 | 0.254000 | AIR | | | |
| 50 | INFINITY | 6.350000 | BASF2 | 1.66446 | 35.83 | ROD 150 |
| 51 | INFINITY | 0.000000 | AIR | | | |
| 52 | INFINITY | 1.000000 | BK7 | 1.51680 | 64.17 | WINDOW 156 |
| 53 | INFINITY | 0.254000 | AIR | | | |
| 54 | INFINITY | 1.000000 | BK7 | 1.51680 | 64.17 | WINDOW 158 |
| 55 | INFINITY | 3.253251 | AIR | | | |
| 56 | INFINITY | 2.540000 | AIR | | | |
| 57 | INFINITY | 2.032000 | SK5 | 1.58913 | 61.27 | LENS 159 |
| 58 | 6.57332 | 2.680977 | F8 | 1.59551 | 39.18 | LENS 160 |
| 59 | -14.12584 | 22.223063 | AIR | | | |
| 60 | INFINITY | 0.000000 | AIR | | | APERTURE STOP |
| | | | | | | LENS 162 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 61 | 9.82357 | 4.572000 | SK16 | 1.62041 | 60.33 | |
| 62 | -3.81000 | 2.032000 | LAF2 | 1.74400 | 44.72 | LENS 164 |
| 63 | INFINITY | 3.623418 | AIR | | | |
| 64 | 8.60409 | 3.810000 | SK5 | 1.58913 | 61.27 | LENS 166 |
| 65 | -8.60409 | 3.621807 | AIR | | | |
| 66 | -2.90783 | 2.032000 | SF11 | 1.78472 | 25.76 | LENS 169 |
| 67 | INFINITY | 12.700000 | AIR | | | |
| 71 | INFINITY | 0.000000 | AIR | | | (IMAGE PLANE) |

The endoscope defined by Table II above has a field of view approximately 68° wide centered on an axis 25° from the optical axis of the probe, and a focal length of 1.3 mm in the anticipated saline environment.

As discussed above, in the detailed descriptions of two preferred embodiments of the endoscope of the invention described by Tables I and II, the ocular comprises one or more movable focusing elements and a number of additional elements. In the embodiments described, these elements are made of glass. The optical elements are equivalent whether made using conventional glass manufacturing techniques including polishing, or made by glass molding techniques now becoming available. At the time of filing of this application, glass molding technology had not matured to the point of suitability for mass production of instruments according to the invention. Therefore, as presently configured, the ocular is anticipated to employ glass elements made using conventional techniques, and will not be sufficiently inexpensive to be cost-effective for single patient disposable use. Should glass molding technology mature such that the ocular can be made cost-effectively using molded glass elements, then likely the ocular will also be disposable together with the probe; this would eliminate sterilization of the ocular prior to surgical procedures. Similarly, the optical design of the ocular might also be modified to employ molded plastic optical elements made using presently available technology, in which case the ocular could also be made disposable.

In a further embodiment of the invention, the transfer module is coupled to conventional video camera not by a focusing ocular as described above, but by an afocal coupler interfacing the transfer module to a conventional focusing ocular and video camera, that is, to an ocular used to couple a conventional non-disposable endoscope probe to a video camera providing images for display on a video screen. Use of a coupler would allow the disposable endoscope probe according to the invention to be used with preexisting

ocular and video camera components now available in hospital environments. An example of this embodiment of the invention is shown in Fig. 18.

As shown in Fig. 18, a transfer module 228 which may correspond generally to either of the transfer modules discussed in detail above is terminated by a window 256. A coupler 280 comprises a window 258 juxtaposed to the window 256 at the proximal end of the transfer module 228. The coupler 280 includes (for example) optical components 262, 264, 266 and 268, as necessary to correct the aberration in the image provided to the coupler 280 from the transfer module 228, in accordance with the objects and advantages of the invention discussed above. The coupler 280 may also include an aperture stop 261 as shown. However, the coupler is not provided with a movable focusing element as was the case with oculars 20 and 120 discussed above; accordingly, the ocular is termed "afocal". Instead, a movable focusing element 282 is provided in a conventional ocular 284, "conventional" in that ocular 284 is also satisfactory for connecting a video camera 292 to a conventional non-disposable endoscope probe. Ocular 284 will typically comprise a window 286 for mating with a corresponding window 288 of the coupler 280. A CCD imaging chip 290 and filter and window elements 70, 71 and 72 as generally discussed above, are comprised by the conventional video camera 292.

Thus, in the embodiment of Fig. 18 aberration in the image provided at the proximal end of the transfer module 228 is corrected by optical components 262, 264, 266 and 268 included in the coupler 280, such that a substantially corrected image is presented to a conventional ocular 284 for imaging by a camera 292 or the equivalent.

As indicated this embodiment has the advantage that a conventional ocular 284 can be employed, saving somewhat on the cost of conversion to use of the disposable probe of the present invention.

The coupler 280 may be provided as an integral part of the probe or may be a separate member assembled thereto.

Similarly, the coupler 280 may be disposable or non-disposable depending on the materials of and the techniques used to form its elements, as discussed above.

Numerous conventional techniques may be of use in practicing the invention. For example, it is well known to coat optical surfaces at which an air gap exists with an antireflection coating, to minimize light loss. Known multi-layer dielectric coatings are preferred for this purpose; a magnesium fluoride film of approximately 137.5 nm thickness, that is, equal to one-quarter the wavelength of light in the center of the band to be collected, is also satisfactory. The circumferential surfaces of the various elements may be blackened to absorb stray light. The outer peripheral surfaces of each of the elements are cylindrical, specifically 6.5 mm diameter in the laparoscopic embodiment and 3.0 mm in the arthroscopic embodiment, so that the probe may be assembled simply by inserting the elements in sequence into the bore of a tube. These and other aspects of practice of the invention are within the skill of the art.

The design of the endoscope according to the invention having thus been specified in detail, its advantages and improvements over the prior art can now effectively be summarized.

According to an important aspect of the invention, most of the surfaces of the glass elements of disposable probe 10 are planar. The sole exception is the spherical surface $S_2$ formed in distal window element 34. The remaining elements of disposable probe 10 having curved optical surfaces are inexpensively molded of plastic. While the optical elements of ocular 20 are of glass, the ocular need not be disposable together with the probe, such that the cost of ocular 20 need not contribute significantly to the per-use cost of the endoscope according to the invention. Further, as noted, in time molded glass lenses may become economically attractive, such that an ocular using glass elements might be made

disposable. Alternatively, a disposable ocular might be made using molded plastic elements.

The preferred design specified above includes a number of molded plastic lenses having aspheric surfaces which are relatively easy to form using presently available technology. As noted, as glass molding technology matures, it may become desirable to mold some or all of the lenses of the probe of glass. It will be recognized that some of the aspheric surfaces could also be eliminated through use of appropriate nonhomogeneous optical materials, that is, materials exhibiting gradients in their index of refraction. Elements employing these materials are intended to be included within the claims of this application where not specifically excluded.

It will also be appreciated by those of skill in the art that the use of an integrally molded prism according to the invention provides substantial economy as compared to the complex prism fabrication techniques employed in the prior art. According to the invention, endoscopes comprising prisms molded of plastic can be manufactured at sufficiently low cost to be cost-efficient for single-patient, disposable use; in the future it may become preferable to mold the prism of glass.

An important aspect of the method of the invention of forming a visible image of an interior of a body cavity or the like is the step of forming intermediate images between the objective and the transfer module assembly, and between each of the relay modules. Further, as discussed above, the image formed by the objective and thus transmitted to the ocular by the transfer module assembly includes certain predetermined aberration (particularly axial and lateral chromatic aberration, and field curvature) corrected by the ocular according to the method of the invention.

The present invention differs from the prior art in several significant ways. Specific prior patents relating to transfer modules for endoscopes include Hopkins U.S. Patent No. 4,168,882 and Hoogland U.S. Patent Nos.

4,545,652, 4,575,195, 4,946,267 and 4,993,817. In the Hopkins patent two meniscus lenses are arranged on either side of a central cavity, comparable to the entry and exit field lenses forming a cavity between adjacent relay modules in the laparoscopic embodiment of the present invention. However, as indicated above, according to this embodiment of the present invention the field lenses are disposed on either side of a field plane of the system, whereas in Hopkins the lenses are placed around the aperture plane. Those of skill in the art will recognize that the concept of the present invention is thus completely the opposite of that shown by Hopkins, inasmuch as rays from an object point are dispersed at an aperture plane, while rays from an object point converge at a field plane. The teachings of Hopkins are even further afield from the arthroscopic embodiment of the present invention.

The four Hoogland patents are of interest inasmuch as in these patents attempts are made to improve the image quality by placing one lens at the aperture plane and another lens near the field plane. However, Hoogland forces the lenses to be identical and one lens to contact the aperture plane. In the present invention, the doublets of the transfer module are spaced away from the aperture planes by the glass rods of the relay modules, resulting in greater system length and better image quality. More specifically, in the transfer module of the present invention an image produced by the objective is presented to the first field plane of the first transfer group. The first transfer relay module produces an inverted image at the second field plane. The input ray fans and the output ray fans are telecentric to minimize vignetting and maximize relative illumination. An aperture plane is located within each central glass rod, midway between the two doublets of each relay module.

The two doublets of each relay module provide partial correction of the aperture-dependent aberration, and a limited amount of correction of the field-dependent aberration. The doublets primarily correct spherical

aberration and axial chromatic aberration introduced by the transfer module. Lateral chromatic aberration introduced by the transfer modules is canceled out by symmetry about the aperture planes.

The entry and exit field lenses adjacent the field planes in the "laparoscopic" embodiment provide partial aberration correction for the field dependent aberration, primarily Petzval field curvature and astigmatism. The improved correction of these aberrations by addition of the field lenses provides substantial improvement in the image resolution near the edge of the field of view.

In both embodiments, employment of glass rod lenses as part of the transfer module produces a longer instrument length than would be available using lenses of comparable strength spaced by air, or equivalently, reduces the element diameters as compared to a transfer module incorporating air spaces of equivalent length.

A complete endoscope according to the invention as shown in Figs. 2 and 13 (or 17) combines the transfer module of Fig. 4 (or 15) with an objective lens group and a focusing ocular (or the coupler of Fig. 18). The fore-oblique prism of the objective group shown could be replaced by other forms. The image formed by the objective group shown includes partially corrected aberration, particularly lateral chromatic aberration, Petzval field curvature and astigmatism. Some small residual axial chromatic and spherical aberration may also be present. The transfer module combines the objective group aberration with its own aberration. This relatively highly aberrated image is re-imaged onto a CCD camera by an ocular including strong aberration of opposite sign, such that the final image is essentially free of aberration.

In the following claims, it is to be understood that each of the optical elements (apart from the prism) includes first and second optical surfaces, that is, surfaces intersecting the optical axis. The optical surfaces of the various elements are identified by reference to their

respective positions within the probe, for economy of language. Where the claims refer to the specific optical parameters of various components of the probe, the components are identified and specified as in Tables I and II above. For consistency between the Tables and the following claims, the claims defining the invention by recitation of detailed optical specifications also include field planes, aperture planes, field stops, aperture stops, and the like. The terms "optical element" and "element" refer to members having optical power, that is, having at least one curved surface, except where otherwise specified. The term "doublet" refers to a combination of two such optical elements. The term "focusing ocular" is intended to include an afocal coupler in combination with a separate ocular, where not otherwise specified. In the definition of the aspheric surfaces of the various elements of the probe of the invention in the claims, the signs of the values for the aspheric constants A and B are given in relation to the sign of the curvature c of the corresponding element; that is, the signs of constants A, B and c vary with respect to the orientation of the corresponding surface, as shown by Table I. The angles of the reflective surfaces of the prism are specified as in the Tables above.

It will be understood that reference herein to the fact that the probe of the endoscope of the invention is cost-effective for single-patient disposable use should not be construed to limit the invention defined by the following claims, nor to preclude non-disposable, multiple-patient use of the invention.

Inasmuch as the present invention is subject to many variations, modifications and changes in detail, it is intended that all subject matter discussed above or shown in the accompanying drawings be interpreted as illustrative only and not be taken in a limiting sense.

WHAT IS CLAIMED IS:

1. An endoscope for providing an image of the interior of a body cavity or the like, comprising a disposable probe for forming an optical image and a focusing ocular for presenting said optical image to means for forming a visible image, said disposable probe comprising an objective group and a transfer module assembly,

said objective group comprising:

a distal window at the tip of said disposable probe;

a prism adjacent said distal window for defining a viewing angle with respect to an optical axis of said disposable probe; and

a plurality of molded refractive elements adjacent said prism;

said transfer module assembly comprising:

one or more relay modules, each comprising:

a plano-surfaced entry rod;

a first doublet;

a plano-surfaced intermediate rod;

a second doublet; and

a plano-surfaced exit rod;

wherein said optical image formed by said disposable probe includes predetermined aberration; and

said focusing ocular comprises:

axially movable focusing lens means; and

one or more further elements for correcting said predetermined aberration in said image formed by said disposable probe.

2. The endoscope of claim 1, wherein each relay module further comprises an entry field element and an exit field element.

3. The endoscope of claim 2, wherein said exit field element of a first relay module is integral with said entry field element of an adjoining relay module.

4. The endoscope of claim 1, wherein said exit rod of a first relay module is integral with said entry rod of an adjoining relay module.

5. The endoscope of claim 1, wherein the image formed by said probe contains substantial amounts of one or more of field curvature, axial chromatic aberration, lateral chromatic aberration, and astigmatism.

6. The endoscope of claim 5, wherein said one or more further elements of said ocular include a first lens group providing image-forming power and substantial correction of axial chromatic aberration, and a second lens group providing correction of lateral chromatic aberration.

7. The endoscope of claim 6, wherein said second lens group of said ocular further corrects residual astigmatism in the image formed by the probe.

8. The endoscope of claim 6, wherein said axially movable focusing lens means and said first and second lens groups of said ocular each comprise glass elements.

9. The endoscope of claim 1, wherein both of said doublets of each of said relay modules comprise two differing elements, and wherein each of the elements of each of said doublets of each of said relay modules is identical to the corresponding element in the other of the doublets.

10. The endoscope of claim 9, wherein the positions of the elements of said first and second doublets of each of said relay modules are respectively reversed.

11. The endoscope of claim 1, wherein said transfer module assembly comprises an odd number of said relay modules.

12. The endoscope of claim 11, wherein said transfer module assembly comprises at least three of said relay modules.

13. The endoscope of claim 1, wherein said distal window at the tip of the probe is generally planar, having an outer surface of infinite radius, and having a concave spherical surface formed on its inner surface, centered on a normal to the outer planar surface thereof.

14. The endoscope of claim 13, wherein the material of said distal window is glass.

15. The endoscope of claim 1, wherein said prism has first and second reflecting surfaces, and said planar outer surface of said distal window at the tip of said probe and said first and second reflecting surfaces of said prism are located with respect to one another such that a ray entering said distal window along the axis of the field of view of said probe reflects from the first and second reflecting surfaces in sequence and is then disposed on the optical axis of the probe.

16. The endoscope of claim 15, wherein said prism is molded of plastic.

17. The endoscope of claim 15, wherein said prism is a solid member and said reflecting surfaces of said prism are planar surfaces delimiting recesses formed within the prism, such that the reflecting surfaces are interfaces between the material of the prism and air in the recesses.

18. The endoscope of claim 17, wherein a highly reflecting coating is formed on at least the first reflective surface.

19. A disposable probe for forming an image of the interior of a body cavity or the like and intended for use with a focusing ocular group having predetermined optical characteristics, said probe comprising an objective group and a transfer module assembly,

said objective group comprising:

a distal prism for determining the effective viewing angle of said probe with respect to an optical axis of said probe; and

a plurality of molded refractive elements adjacent said prism for optically interfacing said prism to said transfer module assembly; and

said transfer module assembly comprising one or more relay modules, each comprising in sequence:

a plano-surfaced glass entrance rod;

a first doublet consisting of two molded lenses;

at least one plano-surfaced glass intermediate rod;

a second doublet consisting of two molded lenses; and

a plano-surfaced glass exit rod;

wherein the optical image focused by said disposable probe includes predetermined aberration; and

wherein said disposable probe is intended to be used with a focusing ocular group comprising:

an axially movable focusing lens means; and

one or more lenses for correcting said predetermined aberration in the image formed by the disposable probe, and for presenting the image formed by said probe to means for forming a visible image.

20. The disposable probe of claim 19, wherein each relay module further comprises entry and exit field lenses.

21. The disposable probe of claim 20, wherein an exit field element of a first relay module is integral with an entry field element of an adjoining relay module.

22. The disposable probe of claim 19, wherein the exit rod of a first relay module is integral with the entrance rod of an adjoining relay module.

23. The disposable probe of claim 19, wherein the image formed by said disposable probe is substantially corrected with respect to one or more of spherical aberration, coma, and astigmatism, and contains substantial amounts of one or more of field curvature, axial chromatic aberration and lateral chromatic aberration, which are corrected by said ocular group having predetermined optical characteristics.

24. The disposable probe of claim 19, wherein both of said first and second doublets of each of the relay modules comprise two differing elements, and wherein each of the elements of the first and second doublets of each of the relay modules is identical to the corresponding element in the other of said first and second doublets.

25. The disposable probe of claim 24, wherein the positions of the corresponding elements of said first and second doublets of each of said relay modules are respectively reversed.

26. The disposable probe of claim 19, wherein said transfer module assembly comprises an odd number of said relay modules.

27. The disposable probe of claim 26, wherein said transfer module assembly comprises three of said relay modules.

28. The disposable probe of claim 19, further comprising a distal window element at the tip of said probe, said distal window element being generally planar, having an outer surface of infinite radius, and having a concave spherical surface formed on an inner surface, centered on a normal to said outer planar surface thereof.

29. The disposable probe of claim 19, wherein said prism includes first and second reflecting surfaces, and wherein said first and second reflecting surfaces of said prism are located with respect to one another such that a ray entering said prism along a normal to a distal planar surface thereof reflects from said first and second surfaces in sequence, and exits said prism along the optical axis of said probe.

30. The disposable probe of claim 29, wherein said prism is a molded solid member and said reflecting surfaces of said prism are planar surfaces delimiting recesses formed within an outer surface of said prism, such that said reflecting surfaces are formed at interfaces between the material of said prism and air in said recesses.

31. The disposable probe of claim 30, wherein a highly reflective coating is formed on at least said first reflective surface.

32. The disposable probe of claim 19, wherein said molded refractive elements of said objective group comprise identical first and second lenses and a third differing lens.

33. The disposable probe of claim 32, wherein the orientations of said identical first and second plastic lenses of said objective are respectively reversed.

34. The disposable probe of claim 32, wherein each of said three lenses of said objective are molded of optical plastic materials.

35. The disposable probe of claim 32, wherein said objective further comprises a field stop interposed between said third lens and said transfer module assembly.

36. A transfer module assembly for transferring an optical image formed by an endoscope objective to a non-disposable focusing ocular group, comprising one or more relay modules, each comprising in sequence:

a plano-surfaced glass entry rod;

a first doublet;

at least one plano-surfaced glass intermediate rod;

a second doublet; and

a plano-surfaced glass exit rod;

wherein an aperture plane is defined within the glass intermediate rod of each relay group.

37. The transfer module assembly of claim 36, wherein each relay module further comprises an entry field lens and an exit field lens, whereby field planes are defined at the entry and the exit of such relay group.

38. The transfer module assembly of claim 36, wherein said field lenses each comprise at least one aspheric surface.

39. The transfer module assembly of claim 37, wherein the exit field lens of a first relay module and the entry field lens of an adjacent relay module are unitary.

40. The transfer module assembly of claim 36, wherein the exit rod of a first relay module is integral with the entry rod of an adjoining relay module, whereby intermediate

images are formed between said relay modules, within said integral rods.

41. The transfer module assembly of claim 36, wherein each of said first and second doublets of each of the relay modules comprise two differing elements, wherein each of the two elements of each first doublet is identical to the corresponding element of the second doublet, and wherein the doublets of each of said relay modules are identical.

42. The transfer module assembly of claim 41, wherein the positions of the elements of said first and second doublets of each of said relay modules are respectively reversed.

43. The transfer module assembly of claim 36, wherein said transfer module assembly comprises an odd number of said relay modules.

44. The transfer module assembly of claim 43, wherein said transfer module assembly comprises three of said relay modules.

45. A focusing ocular group for connection to an endoscope probe, said probe being capable of forming an image of the interior of a body cavity or the like, said image formed by said probe including substantial predetermined optical aberration, and said ocular group communicating said image to means for forming a visible image, said ocular group comprising:

at least one axially movable focusing element; and

two doublet lens groups;

wherein the optical elements of said focusing ocular group include one or more elements to compensate for said predetermined optical aberration in the image formed by said probe.

46. The focusing ocular group of claim 45, wherein the image formed by said probe is substantially corrected with respect to one or more of spherical aberration and coma, and contains substantial quantities of one or more of field curvature, axial chromatic aberration and lateral chromatic aberration, to be corrected by said ocular group.

47. The focusing ocular group of claim 45, wherein said two doublet lens groups of said ocular group include a first doublet to be disposed toward the probe for providing image forming power and substantial correction for axial chromatic aberration, and a second doublet to be disposed toward said means for forming a visible image for providing correction for lateral chromatic aberration.

48. The focusing ocular group of claim 47, wherein said second doublet further corrects residual astigmatism in the image formed by the probe.

49. An endoscope for being operatively connected to a video camera for imaging the interior of a body cavity, defined by the following prescription for optical surfaces $S_1$ - $S_{34}$ and $S_{78}$ - $S_{89}$ thereof, surface $S_1$ being the distal surface of an objective of said endoscope, surface $S_{89}$ being the proximal surface of an ocular of said endoscope, and surface $S_{93}$ being a light sensitive imaging surface of a video camera operatively connected to said endoscope:

| $S_n$ | Radius (mm) or Aspheric Values | Thickness (mm) | Medium | I.R. | Disp. |
|---|---|---|---|---|---|
| OBJ | INFINITY | 75.000000 | | | |
| 1 | INFINITY | 1.492000 | LAF2-SCHOTT | 1.74400 | 44.72 |
| 2 | 2.35200 | 0.540000 | | | |
| 3 | INFINITY | 3.175000 | NAS30 | 1.56400 | 35.00 |
| 4 | INFINITY (-19.00°) | -0.635000 | REFL | | |
| 5 | INFINITY (+56.00°) | -2.159000 | | | |

| | | | | | |
|---|---|---|---|---|---|
| 6 | INFINITY | 3.556000 | REFL | | |
| 7 | INFINITY | 0.501377 | | | |
| 8 | 6.93464 | 3.429000 | V920 | 1.49200 | 57.40 |
| 9 | -8.54871 | 0.655172 | | | |
| | K: -3.846356 | | | | |
| | A: 0.178981E-03 | | | | |
| | B: 0.490596E-04 | | | | |
| | C = D = 0 | | | | |
| 10 | 8.54871 | 3.429000 | V920 | 1.49200 | 57.40 |
| | K: -3.846356 | | | | |
| | A: -.178981E-03 | | | | |
| | B: -.490596E-04 | | | | |
| | C = D = 0 | | | | |
| 11 | -6.93464 | 0.620078 | | | |
| 12 | -22.07181 | 2.032000 | NAS30 | 1.56400 | 35.00 |
| 13 | 22.07181 | 1.007701 | | | |
| 14 | INFINITY | 3.636480 | | | |
| 15 | INFINITY | 1.750000 | | | |
| 16 | -5.93473 | 3.556000 | V920 | 1.49200 | 57.40 |
| 17 | -5.69019 | 0.179140 | | | |
| | K: -3.628766 | | | | |
| | A: -.241315E-02 | | | | |
| | B: -.691773E-05 | | | | |
| | C = D = 0 | | | | |
| 18 | INFINITY | 30.4800000 | SK5-SCHOTT | 1.58913 | 61.27 |
| 19 | INFINITY | 0.363713 | | | |
| 20 | 21.52290 | 3.048000 | NAS30 | 1.56400 | 35.00 |
| 21 | 7.82682 | 0.000000 | | | |
| 22 | 7.82682 | 3.556000 | V920 | 1.49200 | 57.40 |
| 23 | -22.60502 | 0.370663 | | | |
| 24 | INFINITY | 15.240000 | SK5-SCHOTT | 1.58913 | 61.27 |
| 25 | INFINITY | 15.240000 | SK5-SCHOTT | 1.58913 | 61.27 |
| 26 | INFINITY | 0.370663 | | | |
| 27 | 22.60502 | 3.556000 | V920 | 1.49200 | 57.40 |
| 28 | -7.82682 | 0.000000 | | | |
| 29 | -7.82682 | 3.048000 | NAS30 | 1.56400 | 35.00 |
| 30 | -21.52290 | 0.363713 | | | |

| | | | | | |
|---|---|---|---|---|---|
| 31 | INFINITY | 30.480000 | SK5-SCHOTT | 1.58913 | 61.27 |
| 32 | INFINITY | 0.179140 | | | |
| 33 | 5.69019 | 3.556000 | V920 | 1.49200 | 57.40 |
| | K: -3.628766 | | | | |
| | A: 0.241315E-02 | | | | |
| | B: 0.691773E-05 | | | | |
| | C = D = 0 | | | | |
| 34 | 5.93473 | 1.054699 | | | |
| 78 | INFINITY | 1.524000 | BK7-SCHOTT | 1.51680 | 64.17 |
| 79 | INFINITY | 5.955617 | | | |
| 80 | INFINITY | 5.080000 | BK7-SCHOTT | 1.51680 | 64.17 |
| 81 | -16.65782 | 31.701114 | | | |
| 82 | INFINITY | 0.000000 | | | |
| 83 | 11.15562 | 5.080000 | F1-SCHOTT | 1.62588 | 35.70 |
| 84 | -6.94199 | 2.032000 | SF4-SCHOTT | 1.75520 | 27.58 |
| 85 | 33.50506 | 0.508000 | | | |
| 86 | 5.58277 | 5.080000 | SK5-SCHOTT | 1.58913 | 61.27 |
| 87 | INFINITY | 2.903624 | | | |
| 88 | -3.02007 | 2.032000 | SF11-SCHOTT | 1.78472 | 25.76 |
| 89 | INFINITY | 12.700000 | | | |
| 93 | INFINITY | 0.000000 | | | |

50. The endoscope of claim 49, wherein said surfaces $S_{16}$ - $S_{34}$ define a relay subgroup, said relay subgroup being repeatable to extend the length of a transfer module assembly.

51. A method of transmitting an image from an objective of an endoscope to an ocular thereof, said ocular being spaced from said objective by a transfer module comprising one or more substantially identical relay groups, each said relay group comprising:

a plano-ended entry rod;
a first doublet;
an intermediate plano-ended rod;
a second doublet; and
an plano-ended exit rod;

said method comprising the steps of forming aperture planes at the centers of the intermediate plano-ended rods of each relay group.

52. The method of claim 51, wherein each said relay group further comprises an entry field lens and an exit field lens, whereby field planes are formed at either end of and between each of said relay groups.

53. The method of claim 52, wherein said exit and entry field lenses of adjoining relay groups are unitary elements, and said field planes between said relay groups are formed within said unitary elements.

54. The method of claim 51, wherein said entry and exit rods adjoining relay groups are unitary, whereby intermediate images are formed between said relay groups, within said unitary rods.

55. An endoscope for being operatively connected to a video camera for imaging the interior of a body cavity, defined by the following prescription for optical surfaces $S_1$ - $S_{26}$ and $S_{39}$ - $S_{67}$ thereof, surface $S_1$ being the distal surface of an objective of said endoscope, surface $S_{67}$ being the proximal surface of an ocular of said endoscope, and surface $S_{71}$ being a light sensitive imaging surface of a video camera operatively connected to said endoscope:

| $S_n$ | Radius (mm) or Aspheric Values | Thickness (mm) | Medium | I.R. | Disp. |
|---|---|---|---|---|---|
| 1 | INFINITY | 0.762000 | LAF2 | 1.74400 | 44.72 |
| 2 | 1.17650 | 0.270000 | AIR | | |
| 3 | INFINITY | 1.651000 | NAS30 | 1.56400 | 35.00 |
| 4 | INFINITY (-43.50°) | 1.524000 | REFL (NAS30) | | |
| 5 | INFINITY (+56.00°) | 1.778000 | REFL (NAS30) | | |
| 6 | INFINITY | 0.127000 | AIR | | |

| | | | | |
|---|---|---|---|---|
| 7 | 3.30200 | 2.286000 | PMMA | 1.49200 57.40 |
| 8 | c = -0.249431 | 0.356564 | AIR | |
| | k = -1.026659 | | | |
| | A = 0.491000E-02 | | | |
| | B = 0.133746E-02 | | | |
| | C = D = 0.0 | | | |
| 9 | c = 0.249431 | 2.286000 | PMMA | 1.49200 57.40 |
| | k = -1.026659 | | | |
| | A = -0.491000E-02 | | | |
| | B = -0.133746E-02 | | | |
| | C = D = 0.0 | | | |
| 10 | -3.30200 | 0.241087 | AIR | |
| 11 | -7.12576 | 1.651000 | NAS30 | 1.56400 35.00 |
| 12 | 4.94207 | 1.674264 | AIR | |
| 13 | INFINITY | 1.016000 | AIR | |
| 14 | INFINITY | 12.700000 | BASF2 | 1.66446 35.83 |
| 15 | INFINITY | 0.254000 | AIR | |
| 16 | 9.23300 | 1.778000 | NAS30 | 1.56400 35.00 |
| 17 | 4.33469 | 0.000000 | CEMENT | 1.56000 44.00 |
| 18 | 4.33469 | 2.286000 | PMMA | 1.49200 57.40 |
| 19 | c = -0.121238 | 0.254000 | AIR | |
| | k = -1.317139 | | | |
| | A = -0.269762E-04 | | | |
| | B = 0.681709E-04 | | | |
| | C = D = 0.0 | | | |
| 20 | INFINITY | 28.575000 | BASF2 | 1.66446 35.83 |
| 21 | INFINITY | 0.254000 | AIR | |
| 22 | c = 0.121238 | 2.286000 | PMMA | 1.49200 57.40 |
| | k = -1.317139 | | | |
| | A = 0.269762E-04 | | | |
| | B = -0.681709E-04 | | | |
| | C = D = 0.0 | | | |
| 23 | -4.33469 | 0.000000 | CEMENT | 1.56000 44.00 |
| 24 | -4.33469 | 1.778000 | NAS30 | 1.56400 35.00 |
| 25 | -9.23300 | 0.254000 | AIR | 1.66446 35.83 |
| 26 | INFINITY | 28.575000 | BASF2 | |
| 39 | INFINITY | 0.254000 | AIR | |

| | | | | |
|---|---|---|---|---|
| 40 | 9.23300 | 1.778000 | NAS30 | 1.56400 35.00 |
| 41 | 4.33469 | 0.000000 | CEMENT | 1.56000 44.00 |
| 42 | 4.33469 | 2.286000 | PMMA | 1.49200 57.40 |
| 43 | c = -0.121238<br>k = -1.317139<br>A = -0.269762E-04<br>B = 0.681709E-04<br>C = D = 0.0 | 0.254000 | AIR | |
| 44 | INFINITY | 28.575000 | BASF2 | 1.66446 35.83 |
| 45 | INFINITY | 0.254000 | AIR | |
| 46 | c = 0.121238<br>k = -1.317139<br>A = 0.269762E-04<br>B = -0.681709E-04<br>C = D = 0.0 | 2.286000 | PMMA | 1.49200 57.40 |
| 47 | -4.33469 | 0.000000 | CEMENT | 1.56000 44.00 |
| 48 | -4.33469 | 1.778000 | NAS30 | 1.56400 35.00 |
| 49 | -9.23300 | 0.254000 | AIR | |
| 50 | INFINITY | 6.350000 | BASF2 | 1.66446 35.83 |
| 51 | INFINITY | 0.000000 | AIR | |
| 52 | INFINITY | 1.000000 | BK7 | 1.51680 64.17 |
| 53 | INFINITY | 0.254000 | AIR | |
| 54 | INFINITY | 1.000000 | BK7 | 1.51680 64.17 |
| 55 | INFINITY | 3.253251 | AIR | |
| 56 | INFINITY | 2.540000 | AIR | |
| 57 | INFINITY | 2.032000 | SK5 | 1.58913 61.27 |
| 58 | 6.57332 | 2.680977 | F8 | 1.59551 39.18 |
| 59 | -14.12584 | 22.223063 | AIR | |
| 60 | INFINITY | 0.000000 | AIR | |
| 61 | 9.82357 | 4.572000 | SK16 | 1.62041 60.33 |
| 62 | -3.81000 | 2.032000 | LAF2 | 1.74400 44.72 |
| 63 | INFINITY | 3.623418 | AIR | |
| 64 | 8.60409 | 3.810000 | SK5 | 1.58913 61.27 |
| 65 | -8.60409 | 3.621807 | AIR | |
| 66 | -2.90783 | 2.032000 | SF11 | 1.78472 25.76 |
| 67 | INFINITY | 12.700000 | AIR | |
| 71 | INFINITY | 0.000000 | AIR | (Image Plane) |

56. The endoscope of claim 55, wherein said surfaces $S_{16}$ - $S_{21}$ define a relay subgroup, said relay subgroup being repeatable to extend the length of a transfer module assembly.

57. A disposable probe for an endoscope, comprising an objective and a transfer module assembly, intended for use with a focusing ocular, said disposable probe introducing predetermined aberration into the image presented to the focusing ocular, and said ocular correcting said predetermined aberration in said image.

58. A method for providing a visible image of the interior of a body cavity or the like to an observer, comprising the steps of:

(1) assembling an elongated endoscope probe to a focusing ocular, said elongated probe comprising an image-forming objective and a transfer module assembly;

(2) connecting said focusing ocular to means for presenting a visible image to an observer;

(3) inserting said probe into a portal to juxtapose said objective to the interior of a body cavity or the like;

(4) employing said image-forming objective to form an image of the interior of the body cavity or the like;

(5) employing said transfer module assembly to transfer said image to said ocular, said image transferred to said ocular exhibiting predetermined aberration;

(6) employing said ocular to correct the aberration in said image transferred thereto, and to transfer a corrected image of the interior of the body cavity or the like to said means for presenting a visible image to an observer; and

(7) employing said means for presenting to present a corrected visible image of the interior of the body cavity or the like to the observer.

59. The method of claim 58, wherein said image exhibiting aberration of the interior of the body cavity or

the like transferred to said ocular includes one or more of chromatic aberration, field curvature, and astigmatism to a degree sufficient to render an uncorrected visible image corresponding to said image exhibiting aberration unacceptable, and said step (6) of employing said ocular to correct the aberration in said image exhibiting aberration includes the step of substantially correcting each of said chromatic aberration, field curvature and astigmatism present in said image exhibiting aberration.

60. A method of forming an image of the interior of a body cavity or the like and providing a visible image corresponding thereto, comprising the steps of:

inserting an elongated probe of an endoscope through a portal to juxtapose a distal tip of said probe to the interior of the body cavity or the like;

forming an image of the interior of the body cavity or the like employing an objective disposed at said distal tip of said probe;

employing an elongated transfer module assembly to transfer said image from said objective to a proximal end of said probe, said image transferred to the proximal end of said probe including predetermined aberration;

forming intermediate images exhibiting predetermined aberration at intervals along the length of said elongated transfer module assembly, and at the proximal end of said probe;

coupling an ocular to said proximal end of said probe;

transferring said intermediate image including said predetermined aberration formed at said proximal end of said probe to said ocular;

employing said ocular to correct said intermediate image transferred thereto to remove said predetermined aberration; and

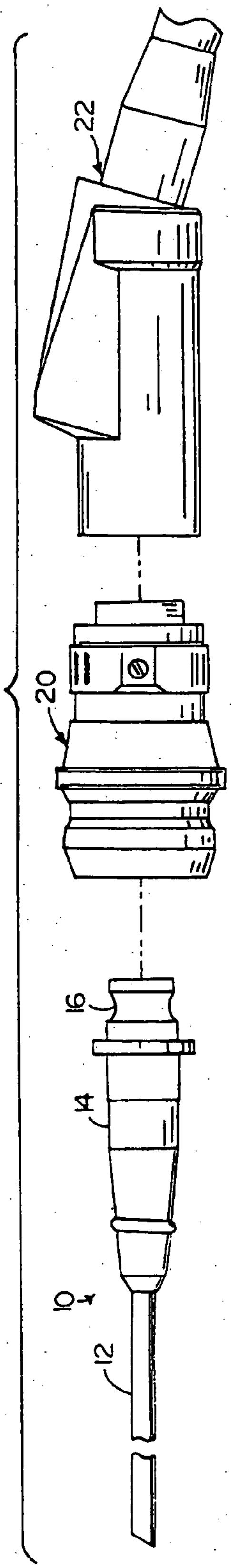
displaying the corrected image on means for displaying a visible image.

61. The method of claim 60, wherein said predetermined aberration included in said intermediate image transferred to said ocular includes one or more of chromatic aberration, field curvature, and astigmatism.

62. The method of claim 60, wherein one or more of said intermediate images formed at intervals along the length of said elongated transfer module assembly are located within solid optical members comprised by said transfer module assembly.

63. A unitary molded prism for an objective group of an elongated endoscope probe for imaging the interior of a body cavity or the like, comprising:

an elongated member molded of an optically transparent material, having a distal planar end inclined at a first angle to the optical axis of a disposable endoscope probe, and a second proximal plano end orthogonal to the optical axis of the probe, and having first and second planar reflective surfaces formed by the inward terminations of first and second recesses in the outer surface of said prism, such that light rays within a field of view of said prism entering said prism at said distal plano end reflect internally within said prism from said first and second reflecting surfaces and exit said prism through said second plano end.


22
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16
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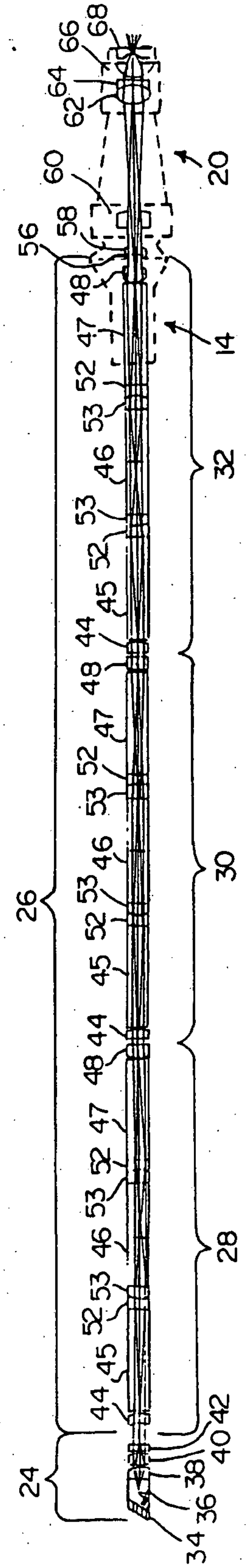
12

FIG 1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68
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62
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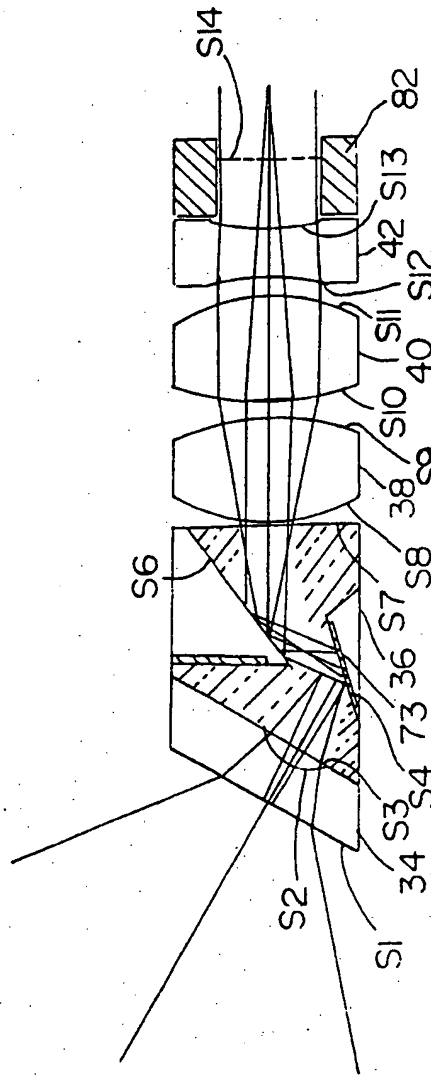
FIG 2

FIG 3


S14
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S13
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S12
S11
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S10
S9
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S8
S7
36
73
S6
S4
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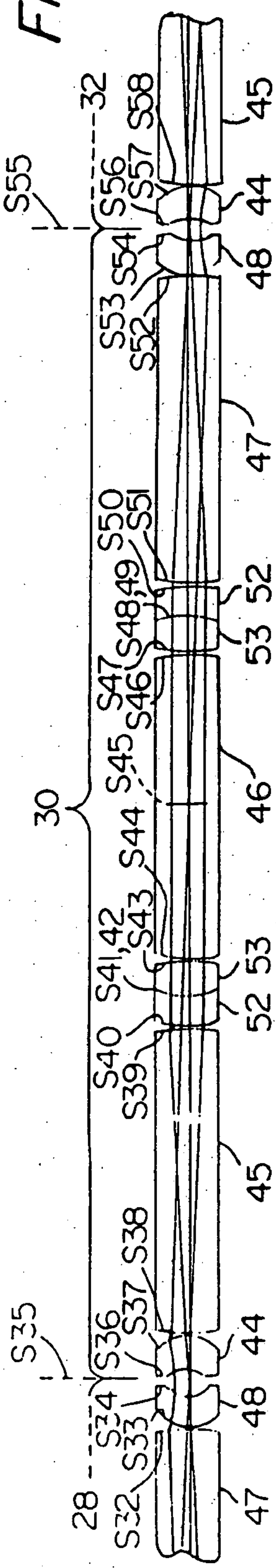
S2
S1
24

FIG 4


32
S58
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S33
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S32
47

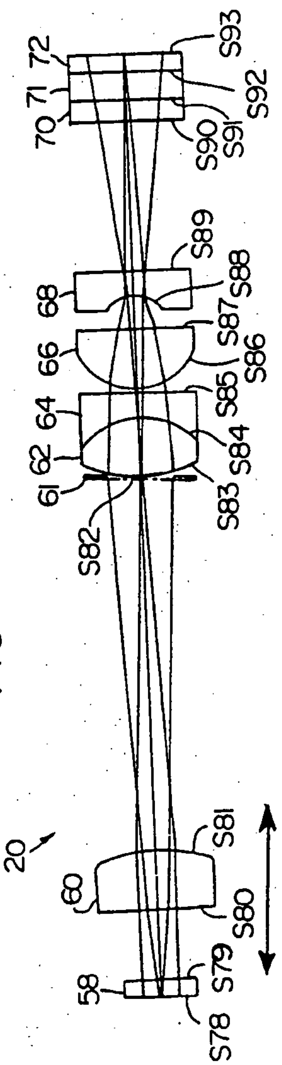



FIG 5

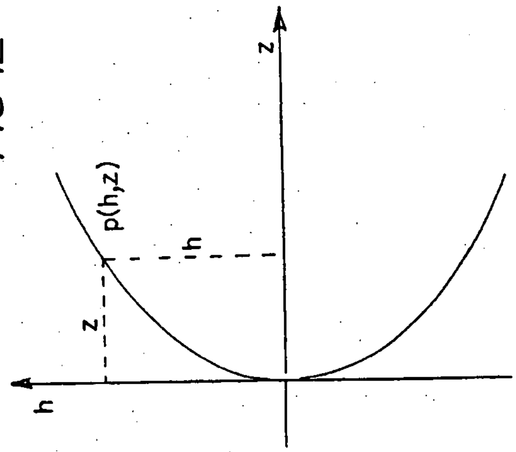



FIG 12

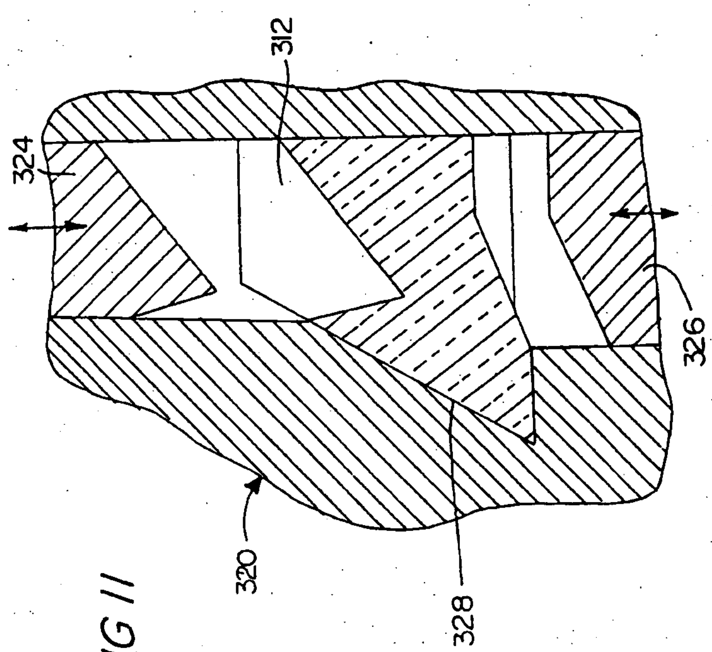



FIG 11

FIG 9

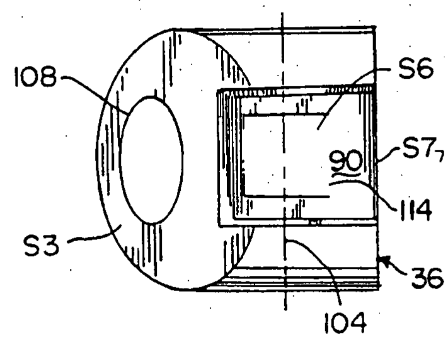



FIG 8

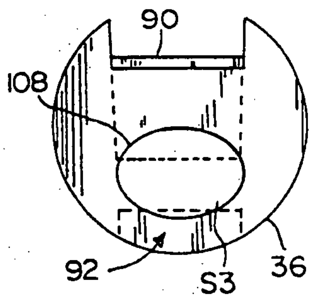



FIG 10

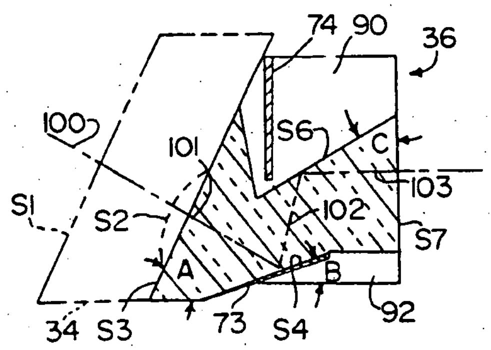



FIG 6

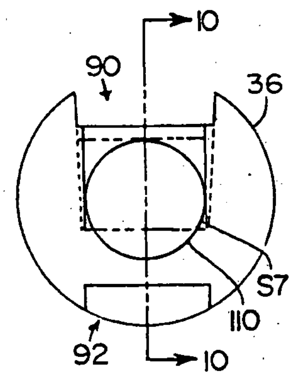
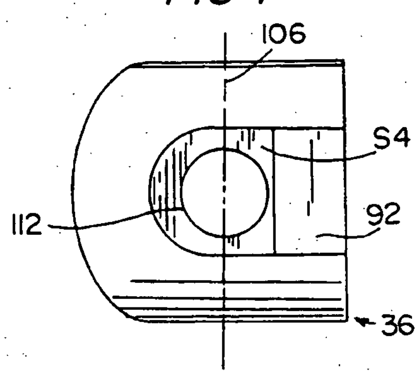



FIG 7



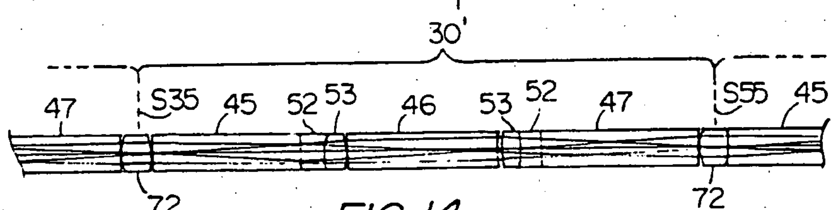
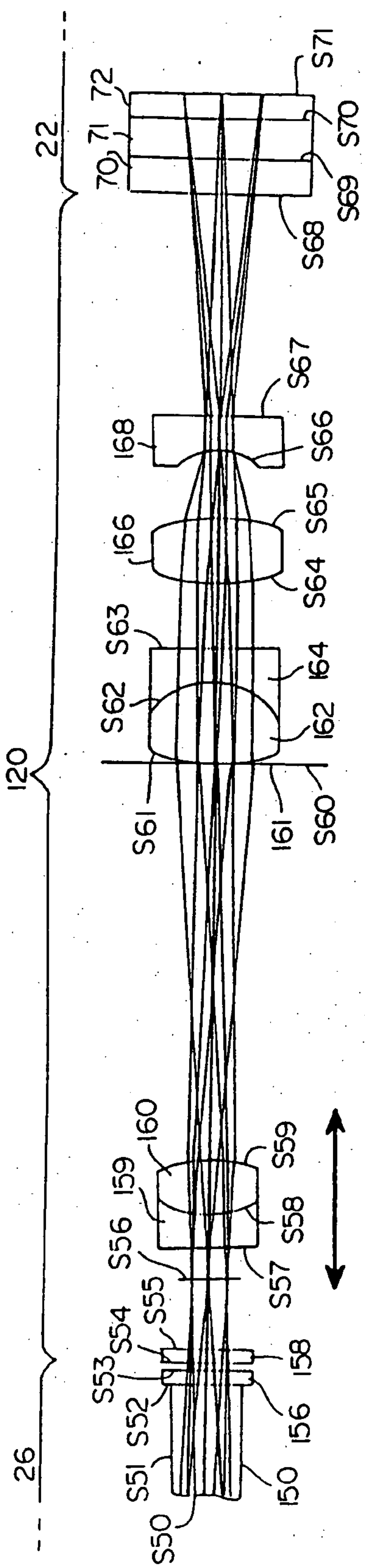




FIG 14


22
26
120
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71
72
150
156
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162
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166
168
S50
S51
S52
S53
S54
S55
S56
S57
S58
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S60
S61
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S63
S64
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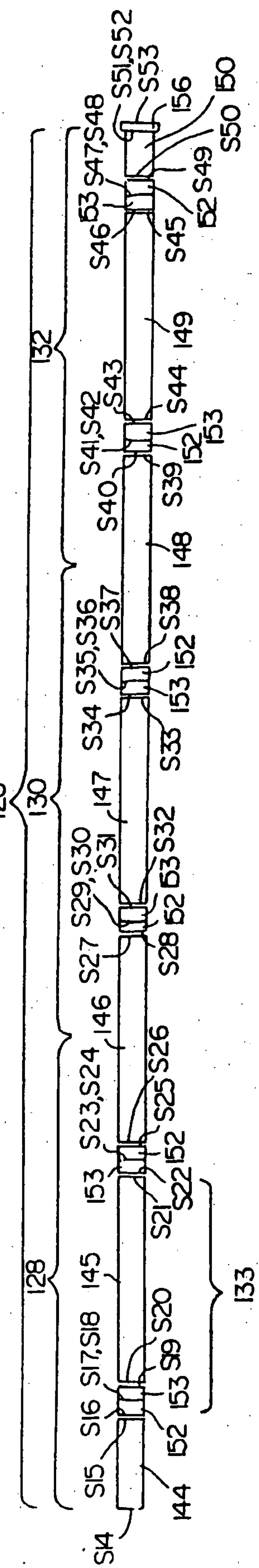
S66
S67
S68
S69
S70
S71

FIG 16


126
128
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152
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S14
S15
S16
S17,S18
S19
S20
S21
S22
S23,S24
S25
S26
S27
S28
S29,S30
S31
S32
S33
S34
S35,S36
S37
S38
S39
S40
S41,S42
S43
S44
S45
S46
S47,S48
S49
S50
S51,S52
S53

FIG 15

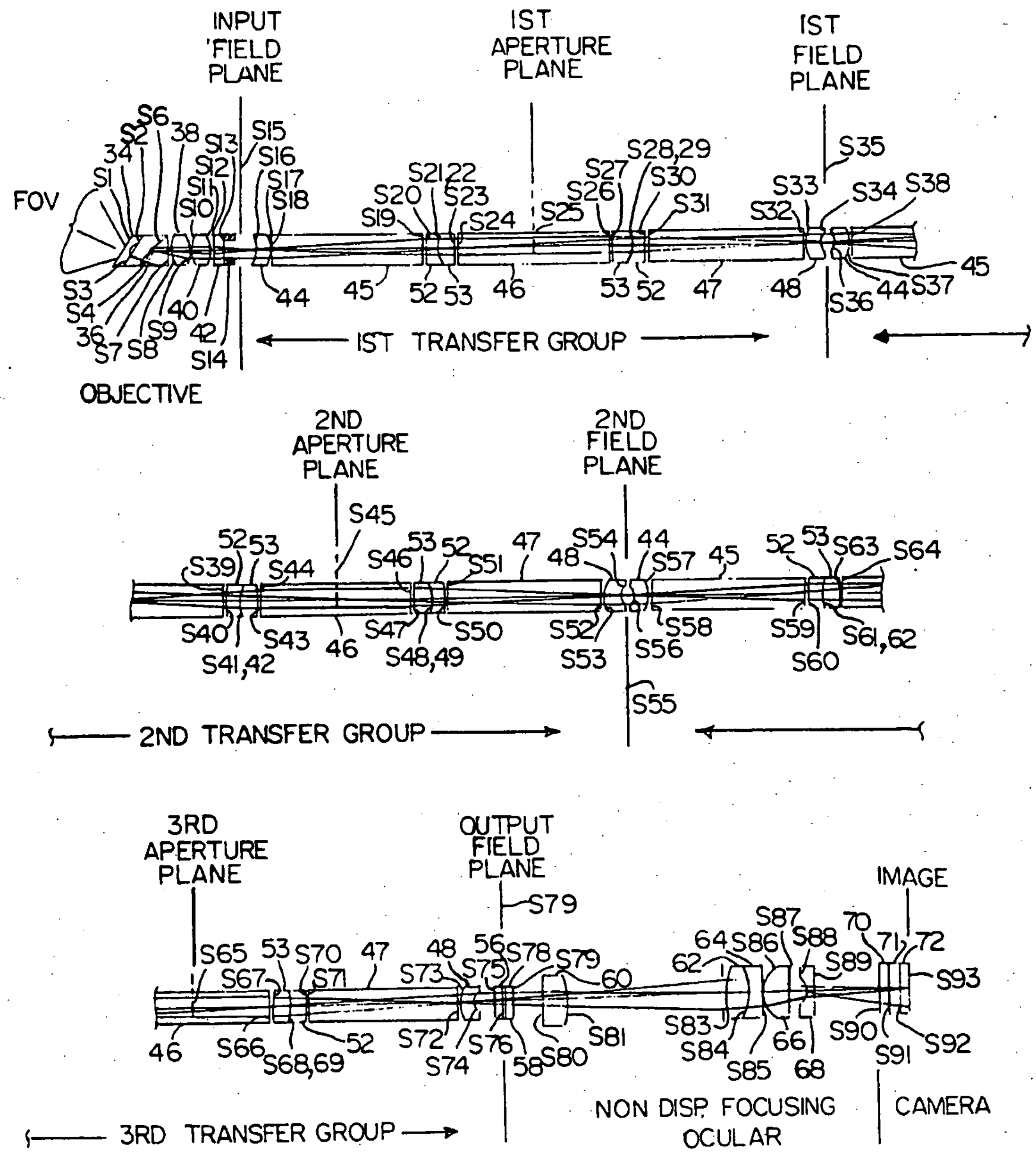
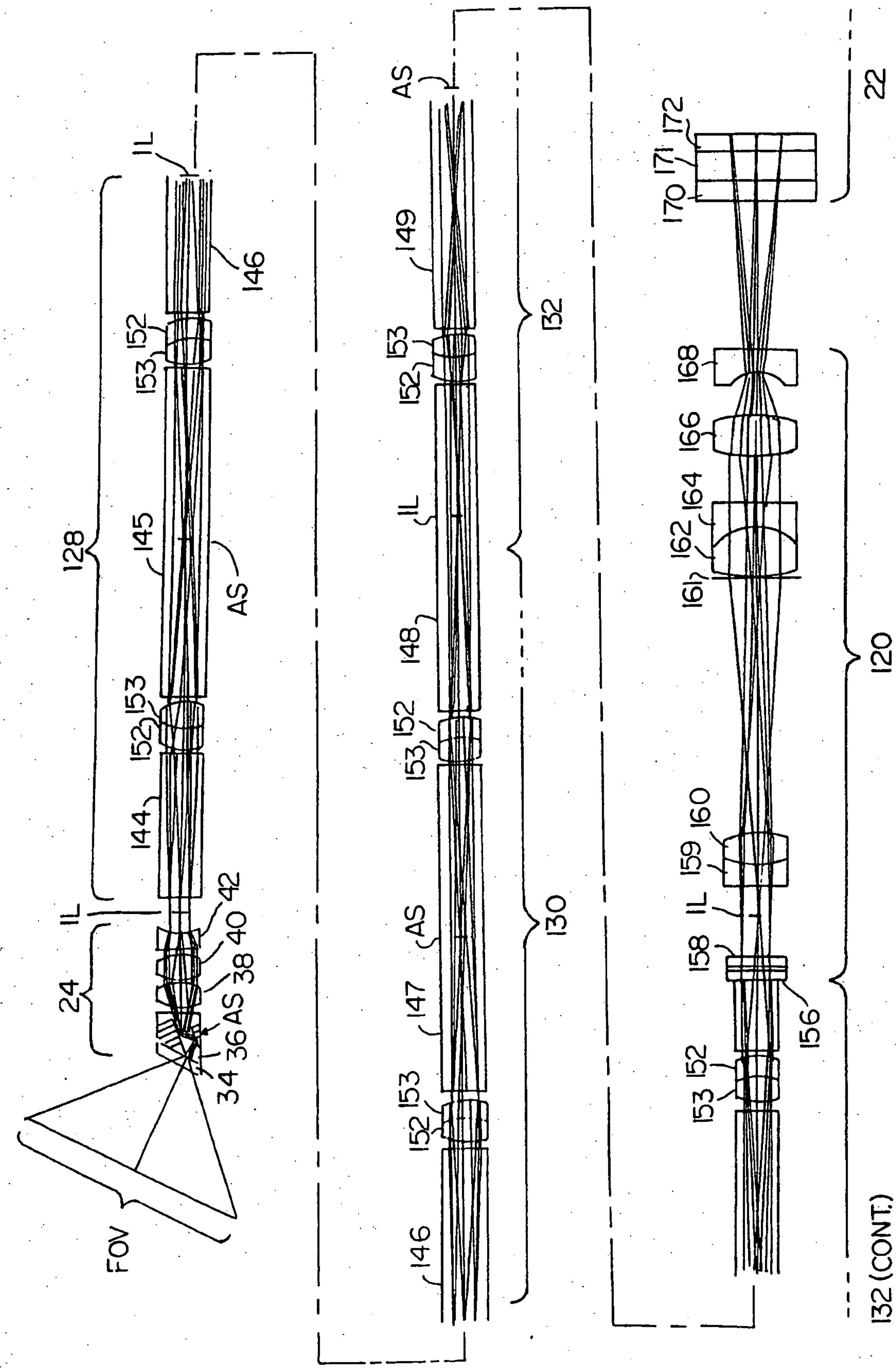

INPUT FIELD PLANE
IST APERTURE PLANE
IST FIELD PLANE
FOV
OBJECTIVE
IST TRANSFER GROUP
2ND APERTURE PLANE
2ND FIELD PLANE
2ND TRANSFER GROUP
3RD APERTURE PLANE
OUTPUT FIELD PLANE
IMAGE
3RD TRANSFER GROUP
NON DISP. FOCUSING OCULAR
CAMERA

FIG 13


FOV
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AS
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IL
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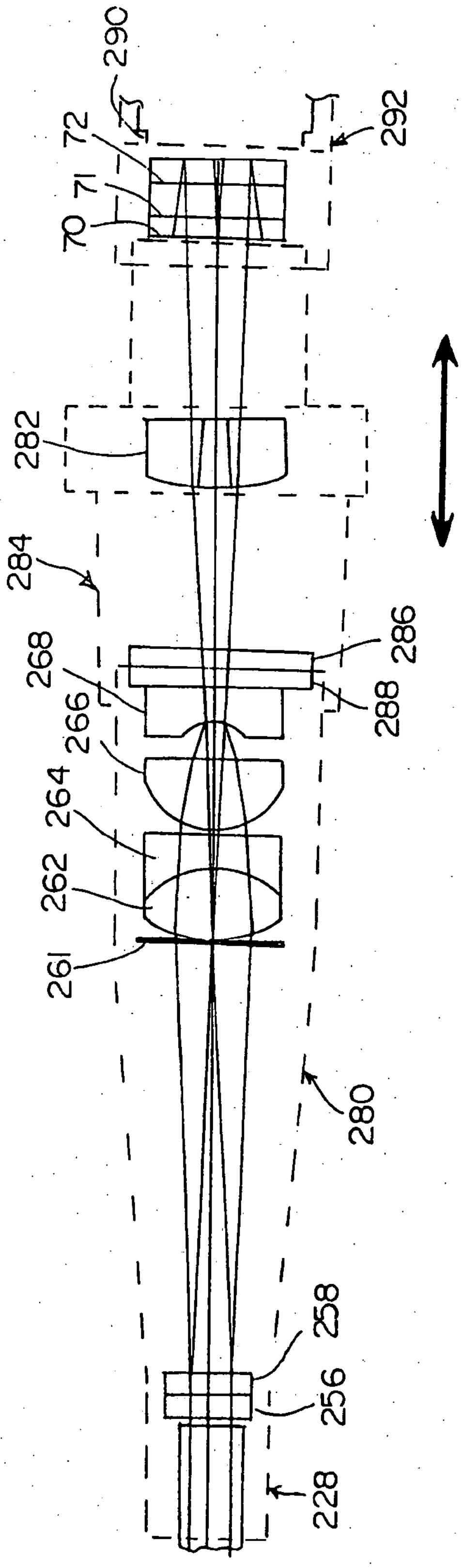
132 (CONT.)

FIG 17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228

FIG 18

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/00515

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :A61B 1/00,1/04; HO4N 7/18; G02B 5/04,23/24,25/00
US CL :358/98; 128/6; 359/434,435,367,643,896,834,645
According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/831,645,643,737,644

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br>Y | US, A, 4,916,534 (TAKAHASHI ET AL.) 10 April 1990, See entire document. | 57-61<br>62 |
| A,P | US, A, 5,142,410 (ONO ET AL.) 25 August 1992, See entire document. | 57-62 |
| Y<br>A | US, A, 4,025,155 (IMAI ET AL.) 24 May 1977, See entire document. | 62<br>1-35,49,50,<br>55-57 |
| Y | US, A, 4,730,909 (TAKAHASHI) 15 March 1988, See entire document. | 63 |
| Y | US, A, 4,815,833 (ZIBEL ET AL.) 28 March 1989, See entire document. | 63 |

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

27 APRIL 1993

Date of mailing of the international search report

12 MAY 1993

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. NOT APPLICABLE

Authorized officer
JON W. HENRY
~~[illegible] NGOC-HO~~
[illegible] DIVISION
Telephone No. (703) 308-4815

Form PCT/ISA/210 (second sheet)(July 1992)★

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | US, A, 4,138,192 (YAMASITA) 06 February 1979, See entire document. | 63 |
| A | US, A, 4,076,018 (HECKELE) 28 February 1978 See entire document. | 1-35,45-50, 55-62 |
| A | US, A, 4,165,917 (YAMASITA ET AL.) 28 August 1979, See entire document. | 1-44,49-56 |
| A | US, A, 4,501,477 (SUNAGA) 26 February 1985, See entire document. | 1-35,45-56 |
| A | US, A, 4,964,710 (LEINER) 23 October 1990, See entire document. | 1-44,49, 50-57 |
| A | US, A, 5,059,004 (MATSUMURA) 22 October 1991, See entire document. | 1-35,45-56 |
| A | US, A, 4,6,24,243 (LOWERY ET AL.) 25 November 1986, See entire document. | 1-35 |
| A | US, A, 4,742,818 (HUGHES ET AL.) 10 May 1988, See entire document. | 1-35 |

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/00515

**Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING

This ISA found multiple inventions as follows:

Group I. Claims 1-35 and 49-57 drawn to an endoscope including a prism, objective, transfer assembly, and ocular in varying detail and a related method classified in class 359/3671.

Group II. Claims 36-44 drawn to a transfer assembly in varying detail classified in class 359/434.

Group III. Claims 45-48 drawn to an ocular in varying detail classified in class 359/643.

Group IV. Claims 58-62 drawn to a method of providing a visible image classified in class 359/896.

Group V. Claim 63 drawn to a prism classified in class 359/831.

The claims of these five groups are directed to different inventions which are not linked to form a single inventive concept. The claims of the five groups are distinguished by either separate details or claims of varying breadth which evidence that none of the inventions as a whole are distinguished by any same "special technical feature".